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Heat Transmission in Rotary Kilns.—I.

By W. GILBERT, Wh.Sc., M.Inst.C.E.

(1) In this series of articles it is proposed to investigate in detail the manner in which heat is imparted to the material as it travels through the kiln. Owing to the gradual accumulation of the requisite data it now appears that such an investigation will yield results which are valuable in practice. Recent scientific work which has a bearing on the subject includes (*a*) the researches of Dr. Schack in Germany and of Professor Hottel in America in relation to the quantity of heat which can be radiated from the gases H_2O and CO_2 and (*b*) the analysis by the British Fuel Research Board of the published results of a large number of experiments on the rate of heat transfer by convection.

(2) After the available scientific data had been carefully considered by the writer, calculations were made of the rate of heat transmission which obtains in various kilns ranging from 100 to 400 ft. in length and now operating in practice. By a somewhat tedious process of trial and error various formulæ have been verified, or revised, in order to bring them into accord with results obtained by experiment, over the wide range of kilns tested. A method of calculation has been evolved by means of which the effect of size, proportion, and added surface on the output and on the coal consumption can be safely predicted.

(3) For the purpose of a preliminary survey of the results obtained reference is made to a kiln 202 ft. in length which was described in CEMENT AND CEMENT MANUFACTURE for April 1930, when details of a test on this kiln were given, but the following particulars will be found useful:

(*a*) Clinker output per hour ..... 6.97 tons
(*b*) Standard coal consumption, per cent. 31.90
(*c*) Slurry moisture, per cent. 44.6
(*d*) Exit-gas temperature (corrected) ..... 950 deg. F.

Chains or slurry lifters were not used, so that the kiln interior was in effect a plain tube with an increase of diameter in the clinkering zone. A longitudinal

section of the kiln shell, drawn for the sake of clearness to an enlarged vertical scale, is shown in Fig. 1.

For calculation purposes the operation of changing the slurry into clinker is divided into seven stages, as follows:

	Length required in kiln (ft.)
Stage (1) in which the temperature of the slurry is raised from 60 deg. to 212 deg. F.	39.4
Stage (2) in which the slurry moisture is evaporated from and at 212 deg. F.	100.3
Stage (3) in which the dry raw material is raised in temperature from 212 deg. F. to 1,300 deg. F.	11.8
Stage (4) in which the $CaCO_3$ is decomposed and the material temperature rises from 1,300 deg. to 1,700 deg. F.	23.4
Stage (5) in which the material to be clinkered is raised in temperature from 1,700 deg. to 1,850 deg. F.	1.1
Stage (6) in which the material is raised from 1,850 deg. to 2,450 deg. F. by the heat liberated when clinker is made. (The exothermic reaction assumed is equivalent to a standard coal consumption of 1.35 per cent. on the clinker)	4.0
Stage (7) in which the clinker loses heat by radiation from the kiln shell and is also cooled by incoming air. The coal particles are raised to ignition temperature in this stage	22.0
Total length (ft.)	202.0

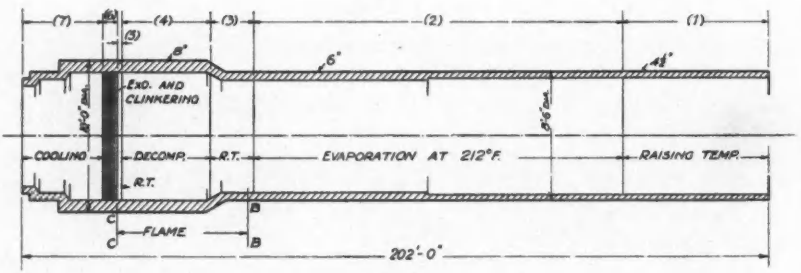

Fig. 1.

In this list of stages, changes in the material state are assumed to take place at definite temperatures; also the position and the amount of the exothermic reaction are fixed. The validity of the various statements made will be discussed later.

(4) The temperatures which obtain in the material and in the gaseous products of combustion throughout the kiln are further illustrated by a graph (Fig. 2). The base line shows the length of the kiln to be divided into 100 parts,

so that the added lengths of the various stages are given as percentages of the total length of the kiln.

Taking first the line of material temperature, the slurry enters the kiln at 60 deg. F. at point *A*. The end of Stage (1) is represented by point *B*, and the end of Stage (2) by point *C* where dry raw material is obtained. It will be noted that the "dry raw material line" occurs at 68.9 per cent. of the length of the kiln.

The temperature of the material now rises, *K* denotes the end of Stage (3), *L* the end of Stage (4), and *M* the end of Stage (5).

The temperature rise due to the exothermic reaction in Stage (6) is indicated by line *M H*, and line *H I* denotes the short length in the kiln where the clinker reaches its maximum temperature, in this case 2,450 deg. F. A reasonable length is assigned to line *H I* since it cannot be fixed exactly, but its position at about 88 per cent. of the length of the kiln shows where clinker was actually made in practice.

Line *I J* indicates the fall of the clinker temperature to 2,160 deg. F. as it passes through Stage (7).

Combustion in the Kiln.

(5) Since the material reaches its maximum temperature at point *H* it is assumed that the transfer of heat from the flame to the material commences at that point. The temperature of the incandescent coal particles is 2,450 deg. F., and the length in the kiln over which combustion takes place is denoted by line *H E*.

To fix the length of line *H E*, the total quantity of heat radiated from the burning particles is calculated, and an estimation is then made of the area of the lining and material surface which must be provided inside the kiln in order that the transfer of this quantity of heat can take place.

(6) The air and gas temperature line commences at point *N*, where the air required for combustion enters the kiln from the cooler or from the coal firing fan at an average temperature of 545 deg. F. During its passage through Stage (7) (the "dead" end of the kiln) the air is further heated by the firebrick lining and by the outgoing clinker, so that a temperature of 589 deg. F. is reached at point *O*.

Line *O P E* indicates the temperature rise due to the progressive transfer of the greater portion of the air supply into the products of combustion, which are the gases CO_2, H_2O, and N_2. The gases generated during the early stages of combustion mix with, and assist to raise the temperature of, the remaining air, and they are cooled by this process. It is assumed that the products of combustion, the CO_2 from the raw material, and the excess air finally attain a common temperature of 2,450 deg. F. at point *E*. As previously mentioned, the validity of the various assumptions made will be discussed later.

Since the burning coal particles finally disappear at point *E*, no further heat is obtained from them, and the gas temperature falls throughout its passage to

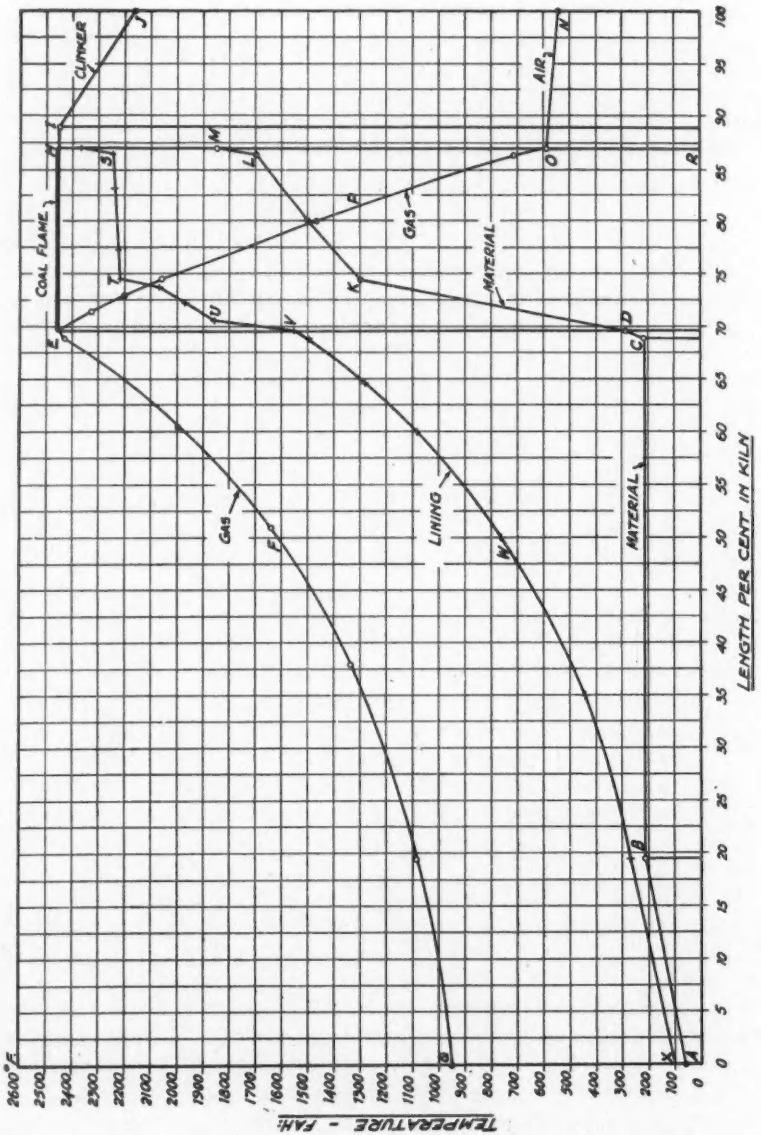
TEMPERATURE - FAHR.
LENGTH PER CENT IN KILN
CLINKER
COAL FLAME
GAS
MATERIAL
AIR
LINING
GAS
MATERIAL

FIG. 2

the upper end of the kiln as denoted by line *E F G*. The waste-gas temperature at *G* (suitably corrected for pyrometer radiation error) is 950 deg. F.

Lining Temperature.

The temperature of the inner surface of the firebrick greatly influences the rate of heat transmission, so that it is necessary to know its value at any point in the length of the kiln. It is possible to calculate it approximately from the known gas and material temperatures in Stages (3) to (7) where the material is dry, but for Stages (1) and (2), in which the wetness of the material surface at any point is uncertain, another method depending on the measured shell temperature and on the thickness of the firebrick lining must be used. For further details reference may be made to an article by the writer in CEMENT AND CEMENT MANUFACTURE, September 1930, para. (27) and Fig. 25.

On the graph (Fig. 2) the temperature of the inner surface of the firebrick lining is denoted by the line *X W V U T S H I J*.

Heat Supply to Material.

(8) It will be seen on referring to Fig. 2 and to the ordinate *D V E* that the heat due to the fall of temperature of the hot gases from 2,450 deg. to 950 deg. F. is sufficient to evaporate the slurry moisture and to raise the temperature of the dry raw material to 282 deg. F. as indicated by point *D*. With small exceptions the remainder of the heat is supplied by radiation from the incandescent coal particles which takes place over the length bounded by the ordinates *D V E* and *R O M H* as previously mentioned.

Put into percentages the methods of heat supply to the material are as follows:

	Per cent.
(*a*) By radiation from gases CO_2 and H_2O	37·3
(*b*) By convection, or direct contact between the hot gases and the kiln lining, or between the hot gases and the material in the kiln	12.0
(*c*) By radiation from the incandescent coal particles	50.7
Total	100.0

The quantity of heat transmitted by gas radiation will be noted. It will be seen later that an increase in the kiln diameter adds to the percentage of heat transmitted by gas radiation and reduces the percentage transmitted by convection.

(9) Paras. (3) to (8) deal generally with the rate at which heat is supplied to a 6 per cent. charge of material, in a kiln 202 ft. long not equipped with chains or slurry lifters. After investigating two or three kilns in the same manner it was found desirable (and satisfactory) to adopt standard values for (a) the flame temperature, (b) the material temperature in the clinkering zone, (c) the exothermic reaction, and (d) the charge in the kiln.

The clinkering-zone flame temperature in different kilns as observed by an optical pyrometer or a Fery radiation pyrometer varied from 2,450 deg. to

2,750 deg. F. The higher temperatures did not usually denote a better kiln, but rather that clinker rings were persistent.

Referring to Fig. 1, the coal particles commence to radiate heat at section CC and cease to do so at section BB, this length corresponding to EH on Fig. 2. For calculation purposes an average value for the flame temperature is required over this portion of the kiln. An optical pyrometer measures the temperature of the flame at or near the cross section CC, but towards the end of the combustion zone it is probable that the flame temperature is reduced in accordance with the lower temperatures of the surrounding lining and the material (see Fig. 2).

The proportion of excess air used does not necessarily affect the flame temperature in the clinkering zone. For instance, the writer observed a temperature of 2,500 deg. F. in one of the early 100-ft. kilns on the wet process where the excess air was 58 per cent., and substantially the same value in a modern kiln 230 ft. long where the excess air was 14 per cent.

As previously mentioned the average flame temperature in the clinkering zone is standardised at 2,450 deg. F. The effect of varying this temperature (within reasonable limits) on the calculated length of the kiln is small.

(10) The material temperature in the clinkering zone is also standardised at 2,450 deg. F. Since the clinker temperature falls as soon as the clinkering zone is passed it is considered that its maximum temperature will not be much less than that of the adjacent flame, since it is still subjected to radiation from it.

(11) With reference to the exothermic reaction during clinkering, for calculation purposes the writer assumes the heat liberated in any kiln to be equivalent to 1.35 lb. of standard coal (or 17,010 B.T.U.'s) per 100 lb. of clinker. Let cTr denote the rise of the material temperature due to the exothermic reaction, and ϕ the specific heat of the material over the range considered. Taking 100 lb. of clinker we have

$$cTr \times 100 \times \phi = 1.35 \times 12{,}600$$

$$\text{hence } cTr = \frac{1.35 \times 12{,}600}{100 \times \phi}$$

Taking ϕ at 0.284, the value of cTr becomes 600 deg. F.

On referring to Fig. 2 it will be seen that the exothermic reaction is assumed to commence at point M where the material temperature is 1,850 deg. F. and its effect is to increase the material temperature by 600 deg. F. For values of the exothermic reaction which have been obtained during the tests on rotary kilns reference may be made to the writer's article in CEMENT AND CEMENT MANUFACTURE for November 1930, para. (61).

Decomposition of the $CaCO_3$.

(12) On Fig. 2 decomposition of the $CaCO_3$ is assumed to occur over the material temperature range 1,300 deg. to 1,700 deg. F. Laboratory experiments made to determine the temperature at which the decomposition of relatively pure lumps of $CaCO_3$ takes place are not altogether relevant, since the cement raw material contains clay and a proportion of coal ash.

Messrs. Lacey & Shirley* have made some interesting experiments in this connection. Samples were withdrawn at intervals along the length of a 102-ft. dry-process kiln, during normal working, through tubes which were built into the firebrick lining. It was found that the $CaCo_3$ had begun to decompose within 15 ft. of the upper end of the kiln, and where the average temperature of the material (as calculated by the writer) could not be more than about 700 deg. F. The kiln exit-gas temperature, however, was from 1,800 to 1,900 deg. F., hence it is probable that the small particles on the surface of the charge became heated to a much higher temperature than the bulk of the material.

The conditions in a wet-process kiln are somewhat similar. It will be seen from Fig. 2 that when the material reaches an average temperature of 1,300 deg. F. at point *K* it has been subjected for some time to radiation from the flame which is at a temperature of 2,450 deg. F.; also the interior surface of the firebrick lining at point *K* is at an average temperature of 2,200 deg. F., hence it is probable that some of the finely divided material has commenced to lose CO_2 before point *K* is reached. The commencement of the exothermic reaction when the average temperature of the bulk of the material is only 1,850 deg. F. may be explained in a similar manner.

Drying the Slurry.

(13) It will be seen from Fig. 2 that the average temperature of the drying material is assumed to remain at 212 deg. F. until all the moisture is evaporated. It must be remembered that any particular lump of slurry is not acted on continuously by the hot gases; during exposure its surface temperature will tend to rise quickly, but for most of the time the lump is buried under other material and its surface is losing temperature to the core. In the example given the time taken for a portion of slurry to pass from *B* to *C* is fifty-nine minutes.

An approximate calculation appears to show that a lump of raw material $\frac{1}{2}$ inch in diameter on arriving at point *C* would have a surface temperature not exceeding 236 deg. F. It will be realised that if the lumps of drying material are assumed to have a higher surface temperature the effective temperature difference for heat transmission would be reduced, and the drying slurry would tend to occupy a greater length of the kiln.

This subject will be again referred to when experiments relating to the surface temperature of drying slurry are completed.

Verification of Fig. 2.

(14) When a rotary kiln has been suddenly stopped under normal working conditions and allowed to cool down, samples for analysis can be taken at various positions in its length. Such an experiment is described by R. Zollinger in CEMENT AND CEMENT MANUFACTURE, April 1932. In this article, Zollinger's Fig. 2 appears to show results which are quite contrary to those indicated by the writer's Fig. 2. At 50 per cent. of the length of the kiln, for instance,

*CEMENT AND CEMENT MANUFACTURE, September, 1932.

Zollinger's Fig. 2 shows the slurry to be apparently dry, and about 5 per cent. of the $CaCO_3$ decomposed, but from the present writer's Fig. 2 the slurry in the corresponding position is about half dry. It appears that the heat stored in the firebrick lining of the kiln is sufficient to explain the discrepancy.

In the kiln to which Fig. 2 relates the conditions at 50 per cent. of the length are:

(*a*) Lining temperature inside	760 deg. F.
(*b*) Lining temperature outside, or shell temperature	255 deg. F.
(*c*) Kiln diameter inside lining	7.5 ft.
(*d*) Thickness of lining	6 in.
(*e*) Estimated slurry moisture	26.5 per cent.
(*f*) Charge 6 per cent., equivalent to dry raw material (per ft. run of kiln)	224 lb.
Water (ditto)	81 lb.

(15) The firebrick will weigh 1,720 lb. per foot run, and its mean temperature is 507 deg. F. Taking the specific heat at 0.23, the total heat of the lining per foot run of kiln reckoned above 212 deg. F. is

$$(507 \text{ deg.} - 212 \text{ deg.}) \times 1{,}720 \times 0.23 = 116{,}800 \text{ B.T.U's.}$$

In addition, there would be a drift of heat from the hotter parts of the kiln.

Since the material is at a temperature of 212 deg. F. the heat required to evaporate the remaining moisture is $81 \times 970 = 78{,}570$ B.T.U's. per foot run of kiln. Hence the heat stored in the lining is probably more than sufficient to produce dry slurry at 50 per cent. of the length should the kiln be suddenly stopped under working conditions.

Some Misconceptions.

(16) It has been stated from time to time that the normal wet-process rotary kiln must always be wasteful in fuel owing to the production of low-grade heat. In the Specification of Patent No. 212298 the same idea is expressed as follows: "The heat available in the gases after leaving the burning zone, the CO_2 zone, and the heating zone will always be more than is necessary to dry the slurry." The patent accordingly describes a method of extracting some of the hot gases from the middle of the kiln for use in waste-heat boilers. The underlying assumption is that if the coal supply is reduced, in order to bring down the kiln exit-gases to a low temperature, the temperature difference available for the supply of heat at the hot end of the kiln may at some point vanish.

(17) This theory does not take into account the considerable proportion of the heat supply which is radiated to the material from the incandescent coal particles at flame temperature. If sufficient surface is added to the interior of a rotary kiln, it is possible to reduce the exit gas temperature to 212 deg. F. The lower limit of coal consumption is then reached.

If the slurry contains 40 per cent. of water, the standard coal consumption will reduce to 19.25 per cent., as shown in the following:

HEAT BALANCE FOR ROTARY KILN.

(Exit gas temperature 212 deg. F.)	Per cent. of clinker
(*a*) Decomposition of the $CaCO_3$	7.16
(*b*) Slurry moisture (raising temperature and evaporation at 212 deg. F.)	8.92
(*c*) Waste gas loss at 212 deg. F.	1.47
(*d*) Kiln and cooler radiation and hot clinker loss, approx.	3.05
	20.60
Less exothermic reaction, say	1.35
Standard coal consumption, per cent. on clinker	19.25

The heat supplied to raise the temperature of the raw material is not included, since it is mostly recovered in the cooler and returned to the kiln in the form of a preheated air supply. The extent to which the cooler fails to recover the heat is allowed for in (*d*).

The heat quantities in (*a*), (*b*), and (*c*) are fundamental to the manufacture of Portland cement by the wet process, and cannot be reduced whatever the type of kiln employed.

(18) Inside the kiln the heat is supplied to the material from two sources:

	Per cent.
(*a*) The kiln gases falling in temperature from 2,450 deg. F. to 212 deg. F.	56.5
(*b*) Flame radiation	43.5

The slurry is evaporated and the dry raw material is raised to a temperature of 1,138 deg. F. by the sensible heat of the kiln gases. The remainder of the heat is supplied by flame radiation, generally as shown on Fig. 2, the temperature difference available for the supply of heat being always substantial.

(19) It has also been suggested that a substantial increase in the flame temperature would (if practicable) enable the coal consumption to be reduced, the underlying assumption again being that there is insufficient temperature difference at the lower end of the kiln. It will be seen, however, from the heat balance in par. (17) that the minimum percentage of standard coal which can be burned in a rotary kiln, when producing clinker, is a definite and known quantity.

The calorific value of the coal would not be increased by raising the flame temperature, neither would the waste gas loss be reduced, hence a substantial increase of the flame temperature would be a step in the wrong direction.

Gas and Material Temperatures by Experiment.

(20) It would be difficult during normal working to measure the gas and material temperatures which obtain along a rotary kiln, and so far the writer has not seen a graph, based on experiment, which appears likely to be correct. By working out the rate of heat transmission from end to end in a number of kilns results are obtained which cannot be far from the truth, although some experimental verification carried out by the aid of apparatus designed for the purpose would be of advantage.

(21) It will be appreciated that the rotary kiln has grown up so far in a somewhat haphazard manner, and it is hoped that the time has now arrived for putting kiln design on a definite scientific basis. The limitations require to be determined, the possibilities made clear, and misconceptions have (after discussion) to be eliminated.

(*To be continued.*)

The Hardening and Corrosion of Cement—II.

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The Hydration of Portland and Aluminous Cements (*continued*).

THE setting of mixtures of Portland and aluminous cements was next investigated microscopically. Klein and Phillips, in their work on the hydration of Portland cement, studied the hydration of a series of mixtures of approximately three parts β dicalcium silicate with one part of tricalcium aluminate, pentacalcium trialuminate, and monocalcium aluminate, respectively. They found that when excess of water was added to these mixtures hydration soon began in the case of all the aluminates with the formation of needles and plates of hydrated tricalcium aluminate. With the $5CaO.3Al_2O_3$ and $CaO.Al_2O_3$ mixtures the formation of amorphous hydrated alumina was later observed. The

Fig. 8.—Portland-aluminous Cement Mixture after 30 mins.

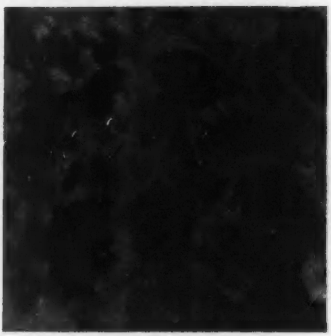


Fig. 9.—Portland-aluminous Cement Mixture shown in Fig. 8 after 3 hours.

hydration of the silicate occurred within two days with formation of a gelatinous substance, which later covered the entire slide. L. S. Wells was unable to confirm these results.

The writer prepared a series of mixtures of aluminous and Portland cements, placed a little of each in turn on a microscope slide, added a little water, and sealed on a cover slip with paraffin so as to prevent evaporation and attack by CO_2. In the case of a mixture of Portland cement and 10 per cent. aluminous cement small needles were formed after five minutes, and they rapidly increased in size and number. These crystals were quite large after fifteen minutes and reached their maximum size in twenty-four hours. With 20 per cent. of aluminous cement the first fine needles appeared after two minutes and increased still more rapidly in size and number. In five minutes they were as large as after fifteen minutes in the first experiment. Again they attained maximum size in twenty-four hours. With 30 per cent. of aluminous cement the first

crystals appeared in one minute and were as large in four minutes as they were in five minutes with 20 per cent. aluminous cement. Figs. 8 and 9 show a mixture of Portland and aluminous cements thirty minutes and three hours respectively after adding water. A comparison of the two photomicrographs shows the growth and multiplication of the crystals.

With pure Portland cement, and with pure aluminous cement, crystal needles do not appear until eight to ten hours have elapsed. It would thus appear in the case of pure Portland cement that the quantity of hydrated aluminate necessary for the production of these needles is only formed after six to eight hours' hydration. With pure aluminous cement six to eight hours must elapse before the hydrolysis of the dicalcium silicate is so far advanced as to set free sufficient $Ca(OH)_2$ to form needles of tricalcium aluminate. It is thus to be expected that a cement which contains only a small quantity of alumina, such as iron ore cement, will require a much longer time of hydration than Portland cement before needle crystals begin to appear.

To test this theory the action of water on iron ore cement, blastfurnace cement, trass cement and Jura-Portland cement was investigated under the microscope. With ore cement it was found that the first minute needles did not appear until after twenty hours, and crystal formation had not progressed appreciably in forty-eight hours. Crystal formation is immensely slower with the low-alumina iron ore cement than with Portland, and is slower still with blastfurnace and trass cements. Indeed with trass cement no crystals can be detected after three days.

The effect of adding aluminous cement to iron ore cement was next investigated, using a mixture containing 10 per cent. of aluminous cement. The appearance of the first small needles was observed after fifteen minutes' hydration, but they did not increase in number so rapidly as in the case of the aluminous-Portland cement mixture, and they grew in size only slowly. After twenty-four hours, however, the crystals were extremely long, being four to five times as large as those obtained with the aluminous-Portland cement mixture. Figs 10 and 11 are photomicrographs of two preparations after different times of hydration, and at different magnifications.

These experiments show that the reaction between the monocalcium aluminate of aluminous cement and the lime of Portland cement (obtained from the hydrolysis of tricalcium silicate), resulting in the formation of dicalcium aluminate, proceeds much more rapidly than the conversion of tricalcium into tetracalcium aluminate. They further confirm the statement made in the preceding article that the only silicate capable of existence in the presence of monocalcium aluminate is dicalcium silicate. Accordingly the addition of a trace of Portland to aluminous cement will have exactly the same effect as the addition of a trace of aluminous to Portland cement, viz., the instant setting of the cement, as shown by Fig. 5; the theoretical conclusions of Erculisse are thus experimentally confirmed.

Extremely quick-setting Portland cements are frequently met with in practice. If these investigations are correct this rapid setting is due to the presence of

monocalcium aluminate, and the question of the origin of this compound arises. The Rankin diagram affords information on this point. According to the diagram the tricalcium aluminate of Portland cement is not stable at high temperatures. At 1455 deg. C. it dissociates into less basic aluminates, e.g., $5CaO.3Al_2O_3$, whose melting point is 1455 deg. C. At still higher temperatures this latter compound dissociates to form lime and monocalcium aluminate, which is stable above 1600 deg. C. The rapid setting of many Portland cements can thus be attributed to overheating the clinker. This overheating need only be very transitory to have effect, since, as we have seen, mere traces of monocalcium aluminate are sufficient to cause instantaneous setting. Traces of this compound are always formed in burning, so that immediately after burning all cements are quick setting. On storage the monocalcium aluminate is transformed partly

Fig. 10.—Iron Ore Cement containing 10 per cent. Aluminous Cement after 24 hours.

Fig. 11.—Iron Ore Cement containing 10 per cent. Aluminous Cement after 3 days.

to $CaCO_3$ and Al_2O_3, and partly to $5CaO.3Al_2O_3$, and the property of quick setting may disappear.

It has been shown that, when Portland-aluminous cement mixtures are hydrated under the microscope, crystal formation begins a few minutes after the addition of water. The presence of such a mixture can be readily detected by this means. It will be interesting to discover whether quick-setting Portland cements, i.e., cements overheated in burning or freshly burnt, also show this immediate crystal formation under microscopic examination. Of a number of quick-setting cements examined, all showed pronounced crystal formation a short time after adding water, and in this case also we have a simple method of detecting such cements by microscopic observation. S. Michelsen[15] has recently introduced a similar microscopic process for determining the hydraulic properties of granulated blastfurnace slags. By means of a catalyst (2 per cent. aluminium

[15] S. Michelsen, *Zement*, No. 25, p. 588, 1931.

sulphate solution) he sets up needle crystal formation in the slag and measures the rapidity of growth of the crystals.

Attempts have often been made to use mixtures of Portland and aluminous cements. It has further been sought to produce a series of cements of varying composition between Portland and aluminous, forming a continuous gradation between the two types. It is, however, only necessary to consider the three-component system $CaO—Al_2O_3—SiO_2$ to realise that this is hopeless. Tricalcium silicate is incompatible with monocalcium aluminate.

It is well known that Portland and aluminous cements react differently to the attack of salt-containing solutions. For instance, aluminous cement is much more resistant than Portland to the attack of sulphate solutions. The behaviour of the two cements in contact with salt solutions will be dealt with in more detail later, but one interesting point will now be considered. Endeavours have been

Fig. 12.—Portland Cement Concrete covered with Aluminous Cement Mortar.

made to utilise the resistance of aluminous cement to sulphates by covering Portland cement concrete with a protective layer of aluminous cement mortar. It was anticipated that the aluminous cement would not be attacked by the sulphate solutions and that the Portland cement concrete would thereby be protected. Experiments along these lines were carried out some years ago in the German Building Research Institute. Cubes of Portland cement concrete, seven days old, were covered with a layer of aluminous cement mortar 2, 4 or 6 cm. thick; the mortar used was mixed in the proportions of 1:1, 1:2, 1:3 or 1:4 of cement and standard sand. After standing for a further seven days the treated cubes were stored in a 15 per cent. $MgSO_4$ solution. In spite of the layer of aluminous cement mortar the cubes were attacked by the salt solution, those covered with the leanest mortar being attacked first, followed by the bodies covered with the 1:3 and 1:2 mortars. The experiments show first of all that aluminous cement

itself causes imperviousness, since aggressive solutions penetrate the lean mixtures more easily than the rich. The cubes covered with the 1:1 mortar are not yet affected, but decomposition is anticipated also in this case.

These results are at first sight unexpected, and it will be interesting to enquire into the chemical reasons for them. It was found that the layer of mortar had in most cases split off from the Portland cement concrete below, so that the aluminous cement mortar, and not the Portland cement concrete, had been attacked (Fig. 12). This indicates that the aluminous cement may have undergone some change during hardening, which can readily be accepted in the light of the foregoing discussion. During the setting of the Portland cement considerable quantities of $Ca(OH)_2$ are formed from the hydrolysis ot tricalcium silicate, and some of this is naturally to be found on the surface of the cement. When the set cement is covered with aluminous cement the latter becomes quick setting

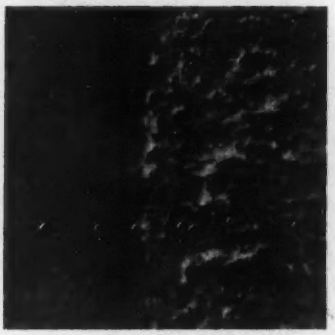


Fig. 13.—Portland Cement with Portland Cement: well-knit junction.

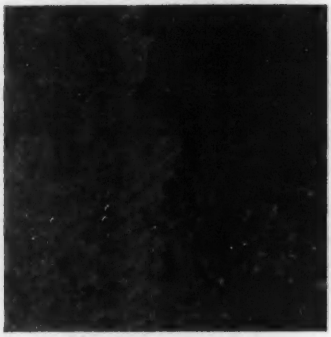
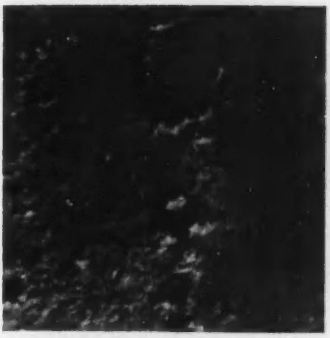
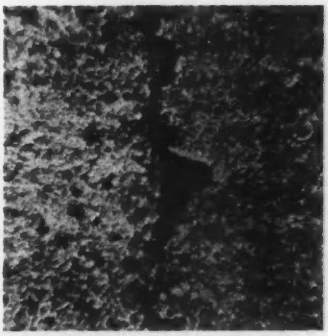


Fig. 14.—Portland Cement with Blast-furnace Cement. The junction is again well-knit.

wherever it comes into contact with this lime, i.e., over the entire surface of contact. The monocalcium aluminate instantly reacts with the lime to form dicalcium aluminate. Thus over the entire area of contact the set aluminous cement develops no strength and does not adhere to the concrete surface. It has already been shown that an addition of monocalcium aluminate or aluminous cement accelerates the hydrolysis of tricalcium silicate, with the separation of lime. This also occurs when freshly mixed aluminous cement is brought into contact with set Portland cement. A renewed vigorous hydrolysis of tricalcium silicate is set up in the surface layers of the Portland cement and lime is formed. This lime penetrates the setting aluminous cement and completely changes it, preventing the normal course of setting by causing gel formation. The dissolved $Ca(OH)_2$ is able to penetrate deeper in the mortars containing less aluminous cement (impermeability of the cement). The leaner the mortar the more will the aluminous cement be rendered quick setting by the lime; such aluminous cement has very little strength and offers no resistance to the attack of salt solutions.

Further to investigate this question tensile test-pieces of pure cement were prepared in which the halves were composed of different cements. The adhesion of the various cements to one another could thus be compared. The test-pieces were prepared by dividing the standard tensile mould into halves with





Figs. 15 and 16.—Portland Cement joined to Aluminous Cement. The darker side is the Aluminous Cement. The dividing surface is deeply fissured.

a piece of sheet iron, and filling one compartment with cement paste of normal consistency. Twelve hours later, when the cement had set, the partition was removed and the other half of the mould was filled with the other cement paste. After a further twenty-four hours the test-pieces were removed from the moulds

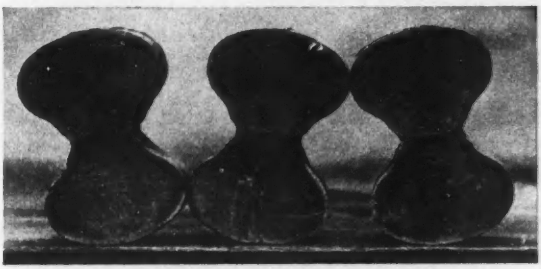


Fig. 17.—Portland Cement united to Portland Cement.

and their tensile strength was determined after seven days. More important than the tensile test results was the microscopic examination of the surfaces separating the two cements, sections of which, at a magnification of 70, are shown in Figs. 13 to 16. Fig. 13 shows the dividing line when both halves of the mould were filled with Portland cement; the junction is quite well-knit and the strength of adhesion good. Fig. 14 shows the junction of Portland and blastfurnace cements, which is again quite well-knit. In these two cases we are dealing with identical or closely related substances, but the position is different when Portland and aluminous cements are brought together (Figs. 15 and 16).

In Fig. 15 Portland cement was first filled into the mould, followed by aluminous cement; in Fig. 16 the aluminous cement was first filled. The results are the same in both cases; there is a well-defined separating layer consisting of granular material of low strength which has rapidly set. The attacking liquid penetrates to this layer and sets up decomposition. Figs. 17 and 18 illustrate the phenomena macroscopically. Fig. 17 shows a number of specimens in which Portland cement is joined to Portland cement. The smooth, well-knit junction of the halves set at different times is clearly seen. Fig. 18 shows the dividing line between Portland and aluminous cements, and the appearance is here very different. There is now a pronounced separating layer marked by a white efflorescence of lime. This affords proof that aluminous cement is wholly unsuitable for use as a protective coating to prevent the attack of Portland cement concrete by salt solutions.

It has been pointed out that when the hydration of small amounts of powdered cement in excess of water is followed microscopically, setting and hardening are seen to proceed with copious crystal formation. It was further found that the pro-

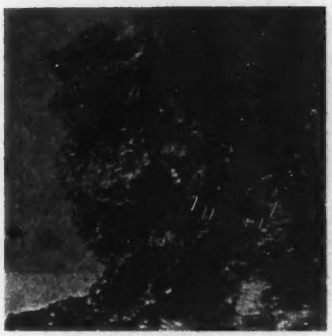
Fig. 18.—Portland Cement united to Aluminous Cement.

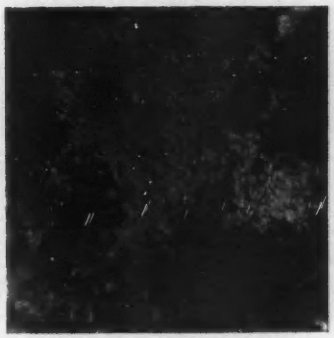
gress of this crystal formation could be used to detect Portland-aluminous cement mixtures, and freshly burnt cement. It will be interesting to ascertain whether these crystals are also formed in set and hardened Portland and aluminous cements mixed with the normal quantity of water (28 to 30 per cent.). The researches of Kühl[16] and of Pulfrich and Link[17] deny the occurrence of crystals in these circumstances. Repeated attempts have been made to bring the normal setting and hardening of cement into agreement with the crystallisation phenomena observed under the microscope, but it seemed desirable again to submit the matter to thorough investigation in the hope of arriving at conclusive results. Accordingly small cubes were prepared from various pure cements, gauging with 26 to 28 per cent. of water. Some of these were stored in water for seven days and others subjected to combined storage for twenty-eight days or two months. Samples were then cut from the centre of these cubes, and from these thin sections of the various cements (viz., normal and high-strength Portland, blastfurnace and aluminous cements) were prepared. In none of these thin sections was

[16] H. Kühl, *Zement*, No. 13, p. 362, 1924; *Tonind. Zeit.*, No. 96, p. 1,690, 1929.
[17] Pulfrich & Link, *Kolloid Zeitsch.*, Vol. 34, p. 117, 1924.

crystal formation found to any considerable extent. In the Portland cements a few small $Ca(OH)_2$ crystals were observed in each case, but there was no sign of any other crystals. In no case was there such copious crystal formation as is evident on microscopic examination of the hydration of powdered cements in excess of water. If there is crystalline structure in cement set under normal conditions, the crystals must accordingly be so small as to be invisible under the microscope. The existence of submicroscopic crystals in normally set cement is quite possible, and indeed probable, but it is unsafe casually to draw an analogy between the microscopic crystals obtained with great excess of water and the hypothetical submicroscopic crystals in normally set cement.

There remains the possibility that any crystals present in the set cement were dissolved, during the grinding of the thin sections, by the water used. To prevent any such solution various liquids were used in grinding the sections, such as





Figs. 19 and 20.—Thin section of Set Cement: age 2 months.

absolute alcohol, benzene and toluene. These gave exactly the same results as water (Figs. 19 and 20). Fig. 19 shows the extremely fine layer of gel in which the coarser cement grains are embedded. Fig. 20 shows a few hexagonal $Ca(OH)_2$ crystals occurring in the gel.

The researches of Kühl and of Pulfrich and Link are thus fully confirmed, and the crystalloid theory of hardening is shown to be improbable. On hydration with large excess of water the cement is completely decomposed into the free hydroxides. The interaction of these gives rise to the numerous crystal types described, and observed also by Ambronn, Keisermann, Blumenthal, Klein and Phillips. If, on the other hand, Portland cement is mixed with the relatively small quantities of water usual in practice, the reaction velocities are different and the character of the reactions is completely changed. In these circumstances the cement is not completely decomposed, and the various crystals observed under the other conditions are not formed. The gel theory of Michaelis thus gains in authority, and it will be our further aim to provide experimental material for the strengthening of this theory.

The New Works of the Green Island Cement Co., Ltd., Hong-Kong.—IV.

By HENRY POOLEY, Junr., B.Sc., Assoc.M.Inst.C.E., A.M.I.Mech.E.
CONSULTING ENGINEER FOR THE PLANT.
(MAIN CONTRACTORS: VICKERS-ARMSTRONGS, LTD.)

Cement Storage and Packing Section.

Eight reinforced concrete silos are provided for storing cement. The height of the silos from the top floor to the ground level is 80 ft. 6 in., while the inside diameter of each silo is 39 ft. 10 in. The bottom of the silos on a cross-section

Part of Weighing and Packing Department.

at right angles to the distribution conveyors is " W "-shaped, and there are three outlets along the bottom of each " V " of the " W," making six outlets per silo in all. The extraction conveyors run in a tunnel under the centre of each row of silos. One of the silos is divided into eight wedge-shaped sections, and a staircase with seven landings is provided through the centre of this silo. Sampling doors are provided to each section of the silo on each landing so that it

is possible for a customer to whom a bin has been allocated to take samples at seven different levels throughout the height of the bin. Each of the seven plain silos has a capacity of approximately 2,100 tons, while each of the eight sections of the divided silo has a capacity of about 190 tons. The roofs of the silos are flat, and the silos are so constructed that each one is separate from the next and does not form a part of the nest. The ground upon which the silos are constructed is reclaimed, and although the reclamation took place some thirty-three years ago it was necessary to drive concrete piles. On top of the piles is a heavily-reinforced concrete mattress, and the silos are built on top of the mattress.

Cement from the elevators discharges on to either of two 18-in. worm conveyors, each 109 ft. long, running over the whole length of the silos, and each driven by a 15-B.H.P. motor through worm-reduction gearing. Each worm conveyor is provided with suitable cast-iron outlets to spout the cement into any of the seven plain silos. Cement can be discharged from these conveyors into a 23-ft. cross-worm conveyor for feeding the divided silo, and this conveyor discharges into a swivelling spout which can be adjusted to feed into any one of the eight small bins. The cement conveying arrangements are duplicated throughout, not only because of standby arrangements, but because two kinds of cement, namely, ordinary Portland and rapid-hardening Portland cement, are manufactured at the same time and distributed to different bins. Under each row of four silos are two worm conveyors (making four in all), each driven through worm-reduction gearing by a 10-B.H.P. motor of 14-in. diameter by 130 ft. long. These conveyors run in an open concrete trough, and the top is covered with a grating. Each silo is provided with six outlets, as already described, feeding the two worm conveyors. The bottom of the silo is approximately 3 ft. from the top of the worm conveyor, and the iron connection between the two is provided with two cut-offs. The upper cut-off, which is near the bottom of the silo, is provided with a wheel, while the bottom one (near the top of the conveyor) is a plain slide. By having two cut-offs in this way, in the event of the cement in any silo arching up, the danger of flooding the tunnel when the arch is being pushed down is minimised; a small poke-hole is provided between the two cut-offs. By running the conveyors in open troughs any cement which spills or floods the tunnel can be easily swept into the conveyor.

The four extraction conveyors feed into two 8-in. diameter cross-worm conveyors, each having a capacity for four mills and each 40 ft. long. These conveyors are driven through worm-reduction gearing by two 7½-B.H.P. motors, and discharge into two totally-enclosed vertical bucket elevators with 18-in. buckets and 54-ft. centres, each driven through gearing by a 10-B.H.P. motor. One elevator is situated at each end of the packing house. These elevators discharge the cement into four reinforced concrete packing hoppers of 30 tons capacity, two at each end of the store. Under each hopper is a set of double 7-in. diameter extracting screws, driven by a 5-B.H.P. motor. From the screws, which are of generous capacity and capable of drawing cement from the hopper at a greater rate than it can be packed by the bagging and barrel machinery,

cement is returned to the cross-worm conveyors feeding the elevators which supply the packing hoppers. In addition, the cement can be spouted from this extraction gear to the first floor where bags are packed, or through to the ground floor where barrels are packed. Under each packing hopper are two sets of platform weighing machines for packing cement into bags on the first floor of the packing house. This makes eight bag-weighing machines in all. The bag used by the Green Island Cement Co. contains 250 lb. and is too large to be handled by a suitable automatic machine. On the platform of each weighing machine is a bag-holding arrangement forming part of the platform on to which the bag is clipped and suspended about 6 in. clear of the platform. A flexible connection connects the spout from the worm-extraction gear under the packing hopper to the bag and when the operator pulls a valve in one direction cement flows into the bag and the weight is indicated on a large dial. When the dial indicates that the bag contains 250 lb. the operator switches over the valve to a spout feeding a second platform machine upon which a bag is in position. While the second bag is filling a coolie inserts the nose of a sack truck under the weighed bag on the first machine and removes it, and another bag is clipped on to the machine ready for the next cycle of operations. The operator becomes skilful in deciding exactly when to switch over the supply of cement, and bags are filled with considerable accuracy by this method. One check-weighing machine is provided, and bags are frequently checked on the scales. The bags are closed by a wire tie and hook twister and sealed, and delivered either into the godown for storage or transported into lorries or lighters. The arrangement works well, and about 15 tons of cement per hour can be packed by each pair of machines, making a total of 60 tons per hour. On the ground floor are four sets of barrel-weighing machines, one for each hopper, by which the amount of cement for the barrel is weighed in a suspended machine with a large dial. The barrels contain 375 lb. of cement, which is spouted into the barrel, which is placed on a joggling machine through a movable skirt while the cement is being filled. There are two joggling machines per weigher operated by a 7½-B.H.P. motor, and each machine can deal with about 7½ tons per hour, making a total of 30 tons per hour for the four machines. The head of the cask is then rapidly put into position, and the casks taken to the godown or directly into lighters. In the packing house a dust-collecting plant of a similar type to that in the cement mill is installed. The main fan is operated by a 22-B.H.P. motor, and dust is collected from all the weighing machinery and returned into the conveyor for packing.

After the packing house was in operation it became evident that there would be a demand for cement packed in paper bags. A Bates 4-valve paper bag packing machine of standard type was therefore installed on the ground floor of the packing house. The hopper was arranged to be fed through a screen by short worm conveyors from either of the cement elevators in the packing house. The belt conveyor for the packed bags runs on the centre line of the packing house in the direction of the wharf, and can be used in the event of a second packer being required at a later date.

(*Continued on page 437.*)

(*Continued from page 436.*)

Tests of the Plant.

Tests were conducted upon various sections of the plant, and some of the results obtained are as follows:

Test of Stone-crushing Plant.—Results of test on No. 2 crusher, inclined belt conveyor, crushing rolls, belt conveyor elevator and distributing belt conveyor, forming one unit of the stone-crushing plant supplied.

Total stone tipped, 78 tons. Total running time, 124 minutes. Time of stop, 18 minutes. Duration of test, 142 minutes. Thus the output of stone during the whole period of the test was 33 tons per hour. Making an allowance of eighteen minutes, and estimating on the running time of the set, the output was 37½ tons per hour.

The size of stone from the crusher was 4 in. and 3 in. down, while from the rolls it was 1 in. down. A proportion of 33 per cent. was retained on the ¾-in. mesh sieve after passing the rolls. The power used during the test as recorded by the crusher and rolls meters was 56.4 KW. and 71.75 KW. respectively. This amounts to 1.64 KW. per ton of stone crushed.

Test on Raw Material Mill.—Result of test performed on No. 2 raw material (wet) grinding mill, 40 ft. by 6 ft. 6 in., on October 28, 1931. The general conditions of the test were as follows: The first compartment was loaded with 3 tons 8 cwt. of 5-in. balls and 3 tons 8 cwt. of 4-in. balls. The second compartment was loaded with 3 tons 19 cwt. of 3-in. balls and 3 tons 19 cwt. of 2-in. balls. The third compartment was loaded with 8 tons 10 cwt. of 1-in. balls and 8 tons 10 cwt. of ¾-in. balls. Total load, 31 tons 14 cwt. The mill speed was 25 R.P.M.

The limestone (Canton) analysis was: Loss on ignition, 41.60 per cent.; silica and sand, 5.17 per cent.; iron and alumina, 0.27 per cent.; lime, 52.33 per cent.; magnesia, 1.11 per cent. The stone was crushed to 1 in. and under by crushers and rolls.

The analysis of the clay (from Kowloon Bay) was: Loss on ignition, 9.84 per cent.; silica, 63.51 per cent.; alumina, 16.60 per cent.; ferric oxide, 4.10 per cent.; lime, 2.76 per cent.; magnesia, 1.77 per cent.; alkalis, 1.42 per cent.; fineness, 11.25 per cent. residue on 180-mesh sieve; fineness, 3.75 per cent. residue on 76-mesh sieve; water, 58.0 per cent.; density, 1.363.

The results of the test were as follows: Duration of test, 8.40 hours. Slurry used, 11 ft. Average fineness, 7.72 per cent. on 180-mesh sieve. Average water content, 35.44 per cent. Average $CaCo_3$, 77.50 per cent. Average density, 1.688. Electricity used, 3,403 units. At 35.5 per cent. water content the dry raw material content per foot run of tank equals 10.978 tons.

The total dry raw material ground was $11 \times 10.978 = 120.75$ tons. Therefore dry material per hour = 14.37 tons. The average fineness was 7.72 per cent.

Ammeter readings were constant at 105 amperes. As 100 amperes is equivalent to 475 B.H.P. in this case, the power supplied to the mill was 500 B.H.P. This represents power absorbed by the mill = 26.1 KW. hours (or 34.8 B.H.P.) per ton of raw material ground. Units used totalled 3,403, that is 28.2 KW. hours (or

37.8 B.H.P.) per ton of raw material ground. Thus the efficiency of the electrical transmission (cables, motor, etc.) was 92.8 per cent.

Test on Cement Mill.—The test on No. 3 cement mill was as follows:

Size of mill, 36 ft. by 6 ft. 6 in. First compartment loaded with 3.25 tons of 5-in. balls and 3.25 tons of 4-in. balls; second compartment, 4 tons of 3-in. balls and 4 tons of 2-in. balls; third compartment, 7.5 tons of 1-in. balls and 7.5 tons of ¾-in. balls. Total load, 29.5 tons. (See later test below for subsequent alteration of grinding media.) Mill speed, 23 R.P.M.

The clinker used was taken from the clinker store where it had been lying only a few hours. In many cases pieces of clinker picked from the mill-feed table were warm.

The test was made on " Emerald " brand ordinary Portland cement, and the results were as follows: Duration of test, 8.67 hours. Clinker ground, 80 tons. Average fineness, 4.65 per cent. on 180-mesh sieve. Average amperes, 84. Gypsum by chemical analysis was 3.39 per cent.; thus the quantity of gypsum ground at the same time was 2.8 tons, and the total cement ground was therefore 82.8 tons.

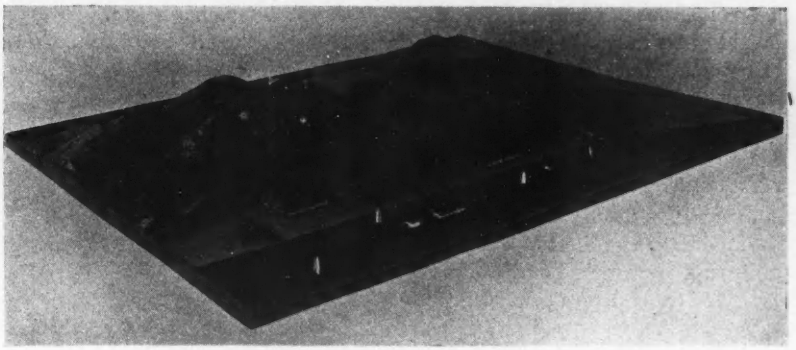
The output of mill was 9.45 tons per hour. Fineness of cement produced was 4.65 per cent. on the 180-mesh sieve.

The power supplied to the mill was 380 B.H.P., or 40 B.H.P./hours per ton; including the electrical transmission the power was 43 B.H.P./hours per ton. KW. supplied to mill=283, or 30 KW./hours per ton; including the electrical transmission the power was 32.5 KW./hours per ton.

Test on Wash-mills and Pumps.—The general conditions were: 14 ft. diameter wash-mills at 25 R.P.M., fed by locomotive crane with clay from Kowloon Bay, containing about 37 per cent. of water. The clay was measured in the clay tank by the dimensions on the internal ladder.

The results of the test were: Duration of test, 1.33 hours. Clay slurry made, 4 ft. Volume of slurry made, 1,456 cub. ft. Weight of dry clay washed, 23.84 tons. Units of electricity used, 34.2 KW. Total dry clay washed was 23.84 tons, and as the duration of the test was 1.33 hours the clay dealt with per hour was 18 tons. Power required per ton of dry clay for one wash-mill and pump was 1.44 KW.

Test on Kiln and Coal Plant.—These tests were made on Nos. 1 and 2 "Reflex" kilns and the air-swept coal plant with auxiliary gear. The ball charges were: primary chamber, 36 cwt. of 3-in. steel balls and 18 cwt. of 2-in. steel balls; secondary chamber, 3 tons of 1-in. cast-iron balls and 3 tons of ¾-in. cast-iron balls. Allowance was made for 0.5 per cent. coal for every 1 per cent. of water above the 36 per cent. specified for the purpose of guaranteed coal consumption. The quantity of clinker was calculated from the quantity of dry raw material contained in the slurry by dividing by 1.53. The clinker weigher acted as a check, but did not operate continuously throughout the test. The proportion of mixed coal used was intended to be two parts of Hongay (anthracite) coal to one part of Miiki (high volatile) coal. Actually the proportions were 1.86:1. The coal con-



Model of the New Works of the Green Island Cement Company, Hong-Kong.

sumption was corrected for excess water over the 36 per cent. allowable in the slurry, for moisture in the coal and for calorific value.

A summary of the results is as follows: Total raw material used, 3,050.30 tons; total Hongay (anthracitic) coal used, 308.7 tons; total Miiki (high volatile) coal used, 165.7 tons; total mixed coal, 474.4 tons. Proportion of Hongay to Miiki coal, 1.86:1.0; average volatile matter in coal, 21.07 per cent.; average B.T.Us. per lb. of coal, 13,300; average moisture, 8.6 per cent.; average ash, 10.86 per cent.; average fixed carbon, 68.49 per cent.

The coal mill ran for 141 hours and ground 3.36 tons per hour. The power used per ton of coal was 25.6 KW./hours.

In the case of kiln No. 1 the average back end temperature was 536.5 deg. F. and the average clinker temperature 211.5 deg. F. In kiln No. 2 the average back end temperature was 554 deg. F., and the average clinker temperature 220 deg. F. The total output was 1,993 tons and the kiln running hours 305, so that the tons per hour were 6.53 for each kiln.

The coal consumption (uncorrected) was 23.80 per cent., and 22.11 per cent. (corrected). The power used per ton of clinker, including firing fan, exhaust fan, and kiln motors, was 13.28 KW hours.

Fine Grinding Test.—On January 20, 1932, a test was carried out on fine grinding, and for this purpose the weights of grinding media were adjusted in the cement mill. It was subsequently found that the new adjustment of the load was better than that previously indicated throughout the tests on ordinary cement.

The mill measured 36 ft. by 6 ft. 6 in. The first compartment was loaded with 1.25 tons of 4-in. balls, 4 tons of 3-in. balls, and 1 ton of 2½-in. balls; the second compartment contained 4 tons of 2-in. balls and 4 tons of 1⅛-in. mild-steel cylpebs; the third compartment contained 8.5 tons of 1-in. cast-iron balls and 8.5 tons of ¾-in. cast-iron balls. The total load was thus 31.25 tons. The mill speed was 23 R.P.M.

The mill was disconnected from the dust plant at the discharge end. A slight draught of 0.1 in. water-gauge was drawn from the feed end. The air passed in the opposite direction to the cement. The mill was water-cooled by a single sprayer. Previous to the test the mill had run for thirteen hours grinding ordinary Portland cement. As in the previous test, clinker was taken from the clinker store where it had been lying only a few hours and was still warm. The gypsum ground is included in the weight of cement bagged. By analysis it was 1.4 per cent.

The duration of the test was 24 hours, and 5.8 tons of cement were ground per hour. The average fineness was 0.99 per cent. on the 180-mesh sieve. An average of 94 amperes (446 H.P.), a total of 8,598 units, were used. The temperature of the cement leaving the mill averaged about 250 deg. Fahr. The power, therefore, amounted to 57.5 KW./hours per ton as supplied to the mill, or 62.0 KW./hours per ton including electrical transmission losses in the motor, etc.

The progress of the work of erection is shown in the following:

October 16, 1929.—Contract placed for machinery, etc.

June, 1930.—Excavations for foundations started.

August, 1930.—First shipment of machinery from England.

September 1, 1931.—Crushing plant started.

September 9, 1931.—Clay wash-mill started.

September 11, 1931.—First raw mill started.

September 18, 1931.—First slurry tank filled.

September 28, 1931.—Coal mill started at 10 a.m.; No. 1 kiln started at 2 p.m.; first clinker produced at 7 p.m.

October 9, 1931.—First cement mill started.

October 12, 1931.—No. 2 kiln started.

October 14, 1931.—Commenced packing and despatching first cement.

January 22, 1932.—Final acceptance and completion certificate issued by the consulting engineer after completion of all tests.

(*Concluded.*)

[*Note.—Manufacturers' announcements regarding the plant at Green Island Cement Works are given in a Special Supplement in this number.*]

Polish Cement Company's Report.

Zjednoczone Fabryki Portland-Cementu "Firley" S.A. showed a loss of approximately £88,800 for the year 1931, compared with a loss of approximately £40,000 for 1930 and a profit of approximately £55,730 for 1929. The last dividend paid was one of 6 per cent. for 1929. *Zement* states that of the sixteen cement factories in Poland only eight were operating during the first six months of the current year, and that these were not working to full capacity.

Tensile Strength Tests of Portland Cement.

By A. C. DAVIS, M.I.Mech.E., M.Inst.C.E.I., F.C.S.

THE strength of Portland cement may be ascertained in pure compression or tension, or a transverse test may be made, in which case shearing stresses will also be taken into account. In actual work the strain to which cement concrete is subjected may be purely tensile or purely compressive, but is more often a transverse strain. Transverse tests are, however, rarely made, the most usual laboratory test for cement, largely for the sake of convenience, being that of its tensile strength. Compression tests are often made, however, and when tests are required of concrete actually used in work they usually take the form of compression tests.

The laboratory tensile strength test as a check upon the quality of cement may be easily applied by simple and familiar apparatus.

There is, however, an increasing demand for compressive tests of concrete and mortar in view of the feeling amongst some engineers that this test is a more useful indication of the strength of their work. It is therefore necessary to keep in mind a distinction between laboratory tests designed as a check upon the quality of cement and tests designed to check the quality of constructional concrete.

Up to the time of writing the tensile strength test, although possibly resulting in illogical and erratic results in the hands of novices, is still regarded as the most convenient for standardised laboratory tests. The tensile test determines the maximum stress per square inch (per square centimetre in Continental practice) which, under given conditions, a standard cement and sand mortar will stand before rupture. If a number of specimens are made individually, and all the standard conditions have been carefully observed for each of them, and yet varying results are obtained, the highest result obtained will be nearest to the correct one. Given accurate weighing of the materials, the highest result could only be too high if sufficient mortar for more than one briquette were gauged at a time and the cement unevenly distributed. Averaging the results is a practice regularly resorted to, but it is not a strictly logical procedure as under the conditions indicated the variations obtained are due to the human factor and not to the cement.

In respect of the uncertainties due to the personal characteristics of the tester and to the influence of local conditions, the tensile test contains possibilities of variations greater than any other British Standard test. The most scrupulous care must be observed in manipulation, and the tester must possess considerable knowledge and experience of such work before reliance can be placed upon his results.

A carefully-made cement and standard sand mortar will sustain high tensile stresses before fracture ; and if the cement withstands the standard accelerated test for soundness then the high strength may certainly be looked upon as an advantage. It used to be thought that high tensile strength at an early age might

be a disadvantage as indicating ultimate disintegration, but since a number of tests are in vogue for discovering expansive tendencies in cement one can by these means readily prove the soundness of the material.

With increased knowledge of the properties of finely-ground cement it is not surprising that the tensile test of neat cement is disappearing, and that an admixture of sand should be almost universally employed in estimating the value of the sample. In the neat tensile test the full value of the cement as a concreting material, or as a cementing power, is never demonstrated, and an inferior cement may in a neat test give tensile strength results equal or even superior to those obtained from a better cement. On the other hand, any difference between the constructive values of cements will be most noticeable in a test carried out with a mixture of aggregate and cement, and generally speaking the more aggregate one uses the more noticeable will be the difference. The value of sand-cement tensile tests in place of neat tests will be more appreciated if it is remembered that cement is rarely, if ever, used in a neat state, except by those who have a wrong impression of its qualities. In a sand-cement test the more practical adhesive and cohesive qualities of the product are ascertained, and its value as a constructive material is demonstrated. Even before it was discontinued as a compulsory British Standard test, many cement specialists had ceased to consider the neat tensile test of importance or practical value.

The experience of those who have spent a considerable part of their life in testing cements seems to show that different cements have their own distinct peculiarities which require to be understood. The strength recorded depends so largely upon details of testing that variations in manipulation among a number of other and minor causes make an appreciable difference in the results.

The following summary includes perhaps most of the common causes of divergent results in the tensile test :

(1) *Cement.*—Whether the cement is fresh or has been aerated ; if the latter, the extent thereof.

(2) *Gauging.*—The amount, quality, character, and temperature of water used in gauging. The temperature of the room. Whether hand or machine mixed. Whether mixing is done on a porous or non-porous material. Quality of the sand used. Accuracy in weighing materials.

(3) *Preparation of Briquettes.*—Whether a skilled operator has been employed. The material of which the mould is composed. The shape of the mould, and the method of filling it. Whether the mould is shaken, tapped, rammed, or pressed to make the briquettes of various densities. Whether the briquettes are kept damp during setting, and whether kept in air or in water during the maturing period. Whether the briquettes are made individually or in batches and by the same operator on the same day and under the same conditions. Temperature of the air and water during gauging, setting, and storage.

(4) *Testing.*—Temperature of the testing room. Length of time the briquettes have been out of water previous to testing. Area of the breaking section and the shape of the cross-section at the point of fracture. Nature of the stress,

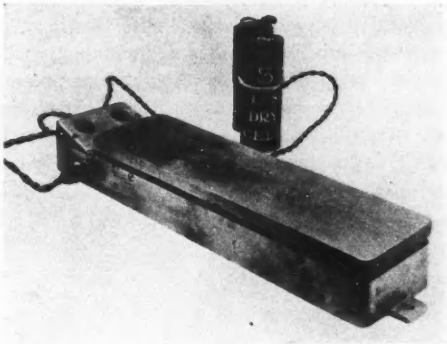


Fig. 1.

and whether suddenly or gradually applied. The form of clips in the testing machine for holding the briquettes. Direction of the strain as regards the breaking sections of the briquettes, and the prevention of cross strains. Unequal bearing of the clips on the briquettes.

It will be seen, then, that there are many factors connected with the making and testing of briquettes, all of which have a distinct and definite influence on the tensile strength recorded.

The percentage of water used in the gauging of 3 : 1 mortar briquettes is generally from 8 to 8½ per cent. of the total weight of sand and cement, according

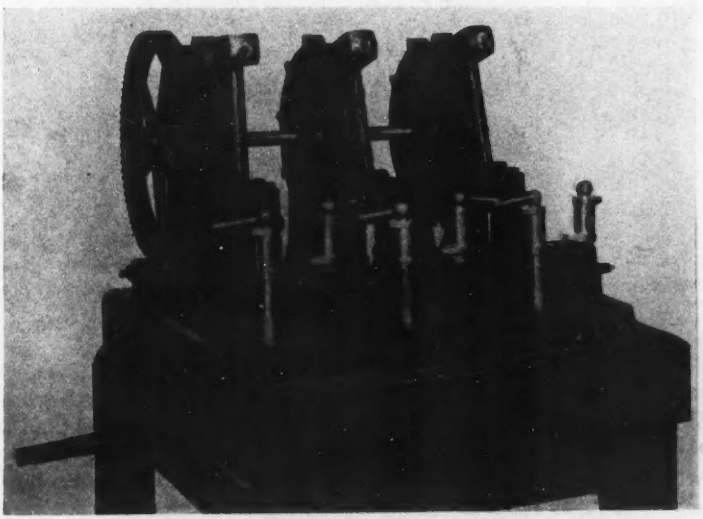


Fig. 2.

to the age, fineness, and activity of the cement. The best results are obtained with a moderate quantity of water, and a stiff plastic mixture gives greater uniformity; if a very wet mix is used it is difficult to keep it homogeneous and uniformly compact in the mould. Recording of the pressure exerted by the operator in filling the mould is sometimes resorted to in an endeavour to control this difficulty with wet mixes, and an American machine for the purpose is illustrated, Fig. 1. This machine is in effect a spring balance with electrical

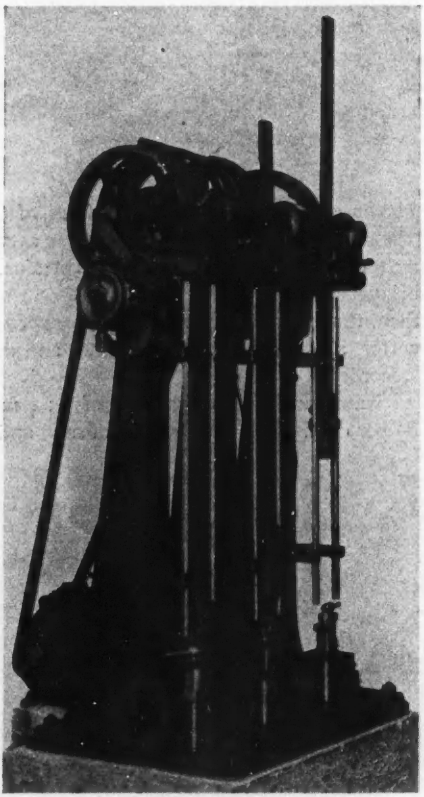


Fig. 3.

contacts so adjusted that while the operator is exerting the desired pressure (usually from 15 to 20 lb.) a white light is shown in the left-hand dial, but if 20 lb. is exceeded then a red light is shown in the right-hand dial.

The water for gauging must be clean and fresh and of a temperature of 58 deg. to 64 deg. F. Particular care must be taken that the mixing is carried out upon a non-absorbent substance, such as slate, marble, or thick glass.

The accurate testing of cements for tensile strength is not a simple process. Some experience is necessary before the materials can be manipulated so as to obtain even approximately accurate results. Tests carried out by inexperienced, though intelligent and careful, persons are usually very contradictory and inaccurate, and no amount of experience can totally eliminate the variations introduced by the personal equation of the operator. However, hammer machines such as those illustrated in Figs. 2 and 3 are used in some countries to avoid these variations, and so far as tests by inexperienced or partially

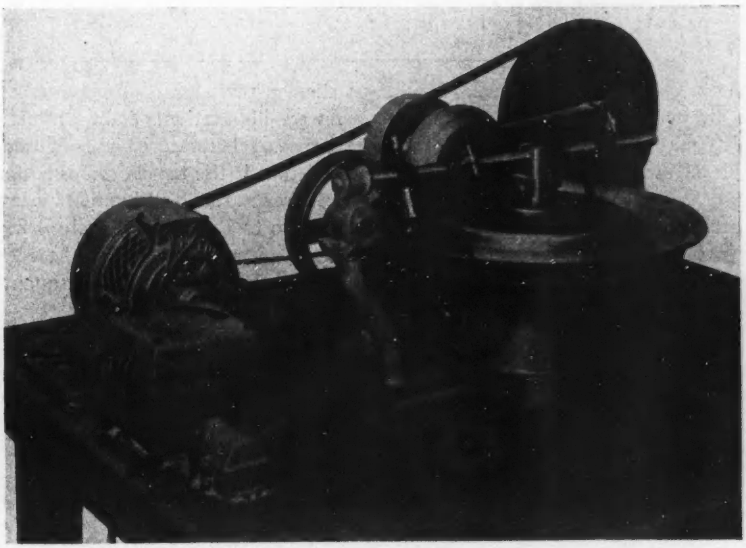


Fig. 4.

experienced persons are concerned they help to ensure uniformity. They do not, however, produce better results than an experienced gauger can obtain by the British Standard method described later. The same remarks apply more or less to the use of machines for mixing the mortar, such as is shown in Fig. 4; this is a Continental machine and is specified in the German normal Specification for Portland Cement, but it has met with little favour in England.

The following is a comparison of tests made by the same expert gauger of a number of cements. In one case the briquettes were compacted with a spatula in the British Standard manner and in the other case they were compacted with the Boehme hammer illustrated in Fig. 2.

Variations between different testers are apt to be more pronounced when tests are made at very short dates, and the introduction of rapid hardening

TABLE I.

SEVEN DAYS TENSILE STRENGTH OF STANDARD 3 : 1 MORTAR.
(lb. per sq. inch.)

Cement.	Compacted with Hand Spatula.	Compacted with Boehme Hammer.
No. 1	540	437
No. 2	473	427
No. 3	548	417
No. 4	570	487
No. 5	513	445
No. 6	505	408
No. 7	630	493
No. 8	577	435

cements, by calling for tensile tests at as short a period as twenty-four hours has brought this fact into prominence. As an illustration of the differences which may be obtained even between experienced laboratories the figures in Table II are given, and it is a fair conclusion that if the tensile test is adopted for such short-period tests present methods of temperature and humidity control as well as other factors affecting results will have to be more precisely defined. It should, however, be stated that these tests were made before the recent issue of a new edition of the B.S.S. with a new method of defining the quantity of water to be used for gauging.

TABLE II.

24-HOUR SAND TENSILE TESTS.
COMPARISON OF RESULTS OBTAINED BY DIFFERENT TESTING LABORATORIES ON FOUR RAPID-HARDENING PORTLAND CEMENTS.
(lb. per sq. inch.)

Laboratory	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.
Cement No. 1 :							
Average	292	238	283	277	243	357	546
Gauging water used (per cent.)	7.81	9.25	9.0	9.0	9.375	8.75	8.375
Cement No. 2 :							
Average	157	131	126	152	135	187	331
Gauging water used (per cent.)	8.12	9.0	8.5	8.375	8.5	8.5	8.0
Cement No. 3 :							
Average	127	119	123	161	160	189	350
Gauging water used (per cent.)	8.12	8.75	8.5	8.375	8.375	8.5	8.0
Cement No. 4 :							
Average	178	203	219	245	282	312	427
Gauging water used (per cent.)	8.12	9.0	9.0	8.25	8.125	8.25	7.75

Standard Test for Tensile Strength (Cement and Sand Mortar).

The British Standard Specification requires that in testing Portland cement for tensile strength the test shall be carried out as follows.

"The breaking strength of cement and sand shall be ascertained from

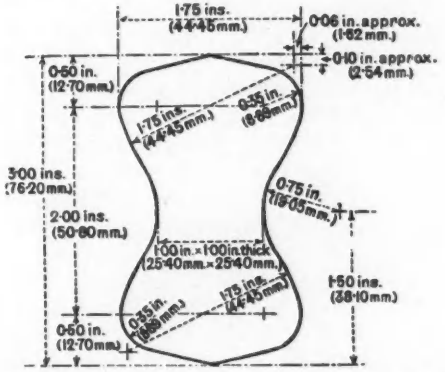


Fig. 5.—Briquette to have a uniform thickness of 1 inch throughout.

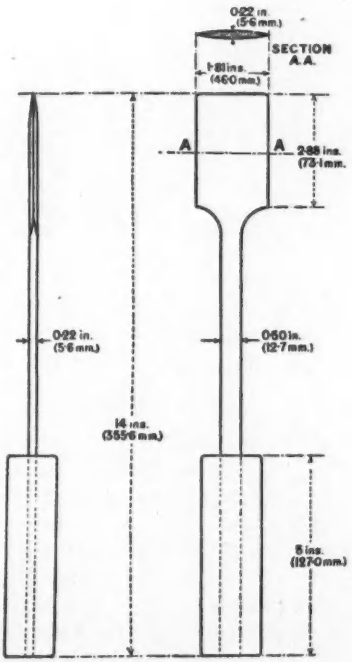


Fig. 6.

briquettes of the shape shown (Fig. 5). The briquettes shall be prepared in the following manner :

" A mixture of cement and sand in the proportion of one part by weight of cement to three parts by weight of the standard sand specified shall be gauged with water, the percentage of water to be used being determined by the formula $\frac{1}{4}P+2.50$ where P is the percentage of water required to produce a paste of normal consistency.

" The mixture, gauged as above, shall be evenly distributed in moulds of the form required to produce briquettes of the shape shown (Fig. 5), each mould

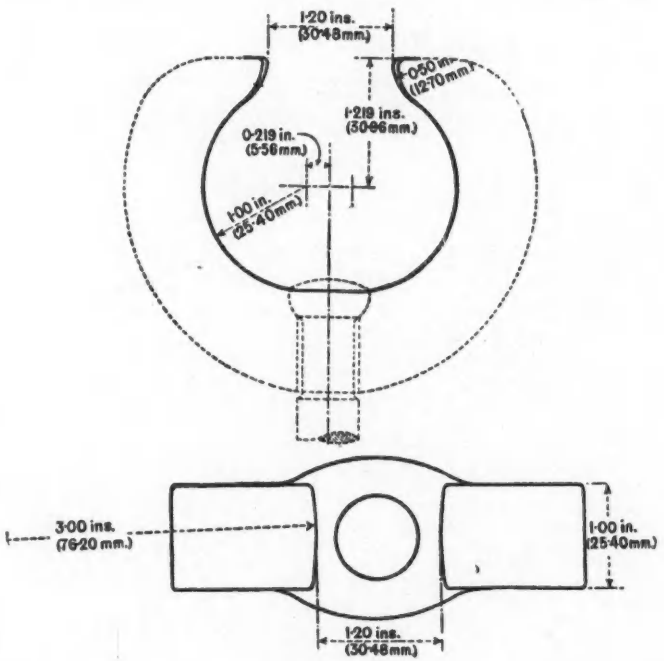


Fig. 7.

resting upon a non-porous plate. After filling a mould a small heap of the mixture shall be placed upon that in the mould and beaten down with the standard spatula (Fig. 6) until the mixture is level with the top of the mould. This last operation shall be repeated on the other side and the mixture beaten down until water appears on the surface ; the flat only of the standard spatula is to be used, and no other instrument or apparatus is to be employed for this operation. The briquettes shall be finished off in the moulds by smoothing the surface with the blade of a trowel.

" Clean appliances shall be used for gauging, and the temperature of the water and that of the test room at the time when the above operations are being performed shall be from 58 to 64 deg. F. (except for hot climates).

" The briquettes shall be kept in an atmosphere of at least 90 per cent. relative humidity for 24 hours after gauging, when they shall be removed from the moulds and immediately submerged in clean, fresh water, and left there until taken out for breaking. The water in which they are submerged shall be renewed every seven days, and maintained at a temperature of between 58 and 64 deg. F. After they have been so taken out and until they are broken, the briquettes shall not be allowed to become dry.

" The briquettes shall be tested for breaking strength at 3 days (72 hours) and 7 days respectively after gauging, six briquettes for each period. The breaking strength shall be the average tensile breaking strength of the six briquettes for each period. The briquettes to be tested shall be held in strong metal jaws of

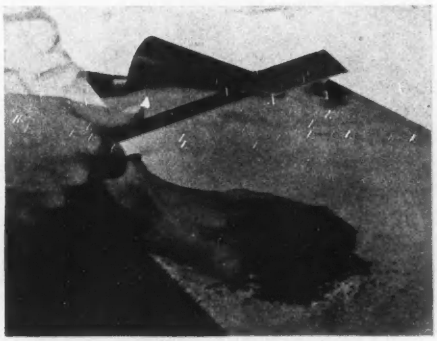


Fig. 8.

the shape shown (Fig. 7) and the load steadily and uniformly applied, starting from zero and increased at the rate of 100 lbs. per square inch of section in 12 seconds.

" *Breaking Strength.*—The breaking strength of the briquettes at 3 days (72 hours) after gauging shall be not less than 300 lb. per square inch of section. The breaking strength of the briquettes at 7 days after gauging shall show an increase on the breaking strength at 3 days, and shall be at least 375 lbs.

" *Standard Sand.*—The standard sand shall be obtained from Leighton Buzzard, shall be of the white variety, and shall be thoroughly washed and dried. Its loss of weight on extraction with hot hydrochloric acid shall not be more than 0.25 per cent. The sand shall pass through a sieve of B.S. mesh No. 18 and be retained on a sieve of B.S. mesh No. 25. The sieves shall be prepared from wire-cloth, complying with the requirements of Table 1 of the British Standard Specification for Test Sieves (B.S.S. No. 410). The wire-cloth shall be woven (not

twilled), and carefully mounted on the frames without distortion. The sieving surface shall be not less than 50 sq. in. (322.58 sq. cm.) and the depth of the sieves shall be not less than $2\frac{3}{4}$ in. (69.85 mm.) measured from the surface of the wire-cloth."

The nominal dimensions and tolerances for wire cloths for sieves for preparing standard sand are given below.

DIMENSIONS OF STANDARD WIRE CLOTHS FOR SIEVES FOR PREPARING STANDARD SAND.

B.S. Mesh No. (nominal meshes per lineal inch).	Nominal size of aperture (side of square).		Nominal diameter of wire.		Standard wire gauge.	Approx. screening area. %	Tolerance on average aperture, plus or minus. %
	in.	mm.	in.	mm.			
25	0.0236	0.599	0.0164	0.417	27	35	5
18	0.0336	0.853	0.022	0.559	24	36	5

The maximum tolerances for occasional large apertures, if present, expressed as percentages of the nominal dimensions for side of aperture in either direction must not exceed 20 per cent. No sieve may be regarded as Standard which does not conform to these requirements."

In the preparation of briquettes all moulds should be made preferably of gun-metal and of the standard shape, and the gauging of each briquette should be carried out in exactly the same manner. As the reliability of the tensile strength test depends mainly upon the preparation of the briquettes it is necessary that precautions be taken so that the personal equation is so far as possible eliminated. Care should be taken that the moulds have been properly cleaned and are placed on small non-porous plates (iron, slate or glass).

For the test, the required quantities of cement and sand for each briquette are weighed (usually 150 grammes of sand and 50 grammes of cement) and turned out in a heap on the gauging slab, where they are thoroughly mixed dry. After the heap has been hollowed out into a crater, the exact amount of water which it has been previously determined will provide the consistency required according to the standard specification is gradually poured on.

The mortar is then thoroughly trowelled and the mould filled, beating down the material with the standard spatula as shown in Fig. 8 so that it is solid and free from air spaces; finally the top side of the briquette is trowelled off flush.

During setting, the briquettes must be placed in a damp box or cupboard with a cloth saturated with water so as to obtain the required humidity, and allowed to remain for twenty-four hours in a place free from vibration. A briquette thus hardened in a saturated atmosphere and kept free from hot or dry draughts may be relied upon to be stronger, and the testing results more uniform, than is the case where by improper treatment the water is evaporated from the mortar

Fig. 9.

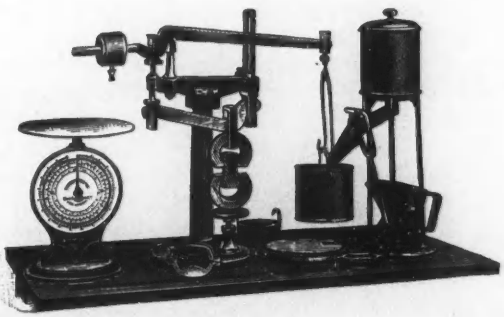


Fig. 10.

too quickly. When the briquettes are thoroughly set they should be immersed in water until required for testing.

Some of the testing machines generally used in this country are illustrated; Fig. 9 shows the "Adie" testing machine with automatic regulator. In this machine the briquette is inserted in the clips and by the use of the automatic regulator the weight is moved gently along until the briquette has broken, the strain being then read on the lever. The automatic regulator has been designed to give a uniform rate of travel to the weight, so that all strains are applied at the standard rate of 500 lb. per minute; but this can be altered to any speed required by means of a cock in the piston. It is also self-acting, and when the test is started it needs no interference whatever; directly the briquette breaks the weight is held fast by means of a clutch or brake until released.

Another type of apparatus for testing the tensile strength of Portland cement is Salter's cement testing machine shown in Fig. 10. This apparatus consists of a japanned cast-iron column, carrying a pair of compound levers having a combined leverage of 50 to 1. The levers are fitted with tempered steel knife edges which rest on polished concave bearings, also of tempered steel, thus obtaining a very sensitive balance. A sliding balance weight for the purpose of setting the levers in equilibrium is fitted to the upper lever. The upper clamp, to receive the cement briquette, is suspended from a knife edge on the lower lever; the lower clamp is attached to the base of the column, and is adjustable by means of a screw and a small handwheel. The supply of shot to the bucket is automatically cut off the moment the briquette breaks. To use the machine, the levers are set "floating" by means of the sliding balance weight. Once set, this need not be touched. The briquette is next placed in the clamps, centrally and flush with the sides. The bucket is hung on the bridle and the hand-wheel screwed up until the top side of the lever from which the shot can be suspended is about half an inch from the top of the guide. This then allows ample downward movement if the clips slide up the briquette as the load increases, and prevents the lever touching the bottom of the guide before rupture, so avoiding the necessity of stopping the machine to screw up the wheel again. As soon as all is ready and all the knife edges are seen to rest square in their bearings, the handle is depressed to the first notch. The shot should be adjusted to apply the load at 500 lb. per minute. As soon as the briquette breaks the bucket falls on to the rubber pad and depresses the lever by which the shutter is released, and so cuts off the supply of shot. All shot must be the same size, No. 6 for preference. The bucket is then removed and placed on the spring balance, by which the breaking load is at once indicated without calculation.

There are other machines used for testing cement for tensile strength, but the two mentioned are typical of machines which have been used for many years. A machine of a later and perhaps more elaborate design incorporating improvements on some earlier types is the Macklow-Smith machine illustrated in Fig. 11.

In regard to tests of cement mortar designed to show the growth of strength with age, the writer has made many series of such tests, usually extending over

a period of years. Standard mortars made from various cements all show the same characteristic fluctuations in tensile strength at intermediate dates with a generally upward tendency, and a typical curve is given in Fig. 12.

A study of the percentage of gain in strength for various periods of time illustrates clearly the important fact that while what were good standard cements of some years ago took an appreciable period to acquire any great strength, the same degree of strength is attained in a very much shorter period by present-day cements, and, of course, still more quickly with rapid-hardening cements.

Tests made with sands all indicate that the tensile strength of mortars made from them decrease with an increase in the percentage of voids, and this is to be expected since strength increases with density and density is greatest for the least percentage of voids. It has therefore to be kept in mind that a sand of

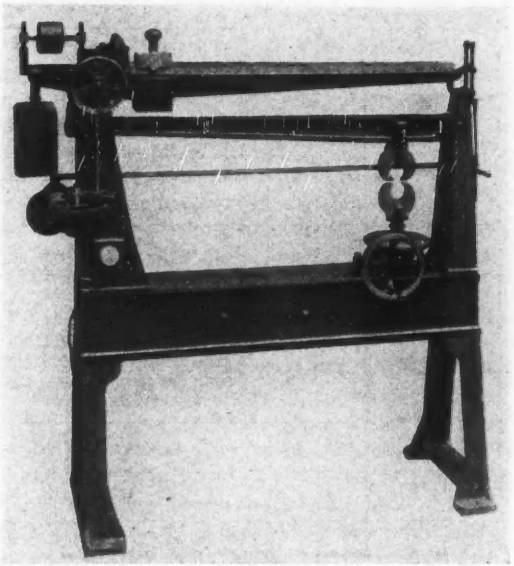


Fig. 11.

uniform size of grain will contain a high percentage of voids and will require more cement for maximum density. For the purpose of securing uniformity of testing standard sand consists of practically one size of grain, and is therefore inferior in this respect to good natural sand for constructional purposes as the uniform size of grain gives a harsh mortar high in voids.

Although it may be said that the tensile strength test of Portland cement is not an ideal test, and that in practice it leads to somewhat divergent results, yet on the whole it has been shown that the better the cement the better will be the strength of it when mixed with aggregate. It is therefore interesting, in

Issue of B.S.S. for Portland Cement.	lb. per sq. in.			Increase from 7 to 28 days must not be less than
	3 days.	7 days.	28 days.	
First, 1904 ..	No test	120	225	20%.
Second, 1907 ..	do.	150	250	20%.
Third, 1910 ..	do.	150	250	25%, 15%, 10% or 5%, according to 7-day result.
Fourth, 1915 ..	do.	200	—	Breaking strength at 7 days. + 10,000 lbs. / Breaking strength at 7 days.
Fifth, 1920 ..	do.	200	—	Ditto ditto
Sixth, 1925 ..	do.	325	—	Ditto ditto
Seventh, 1931 ..	300	375	—	28-day test discontinued in favour of a test at 3 days.

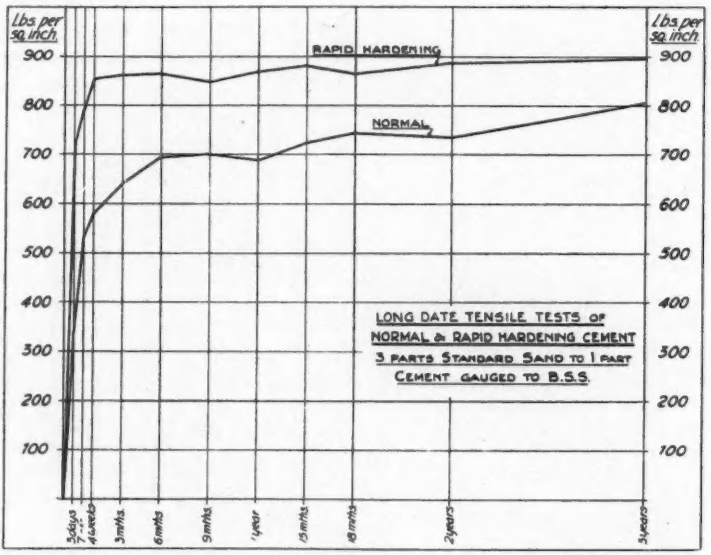


Fig. 12.

considering the progress which has been made in the quality of cement during the last thirty years, to study the following comparison of the increasingly stringent requirements of successive revisions of the British Standard Specification as regards the tensile strength of 3 : 1 standard sand mortar.

Cement Production in Portugal.

Production of Portland cement in Portugal for the period January to July 1932 was 65,292 tons, against 53,088 tons for the same period last year.

Notes from Abroad.

United States Cement Production.

The total production of Portland cement in the United States for the period January to September 1932 amounted to 57,839,000 barrels, against 99,673,000 barrels for the same period in 1931 and 126,917,000 barrels for this period in 1930. The ratio of production to capacity was 30.6 per cent. in September this year, compared with 50.2 per cent. in September 1931 and 65.2 per cent. in September 1930.

Cement Deliveries in Belgium.

A total of 166,000 tons of cement were delivered by Belgian cement manufacturers during the month of August 1932, against 184,600 tons in August 1931. Production is given as 159,300 tons and 203,300 tons respectively for the same month in 1932 and 1931.

Cement in Belgian Congo.

The "Bulletin de l'Office Colonial" states that the capacities of the works of Ciments de Katanga and Soc. des Ciments du Congo are 60,000 to 70,000 and 40,000 tons per annum. The total cement production in Belgian Congo for the year 1931 was 45,937 tons, against 68,296 tons in 1930. Imports of cement were 16,645 tons in 1931 and 31,751 tons in 1930, while exports were 5,094 tons in 1931 against 15,705 tons in 1930.

Belgian Cement Exports.

Exports of cement from Belgium for the month of September 1932 are given as 24,582 tons, compared with 40,614 tons in September 1931.

Cement Production in Canada.

For the period January to May 1932 the production of cement in Canada amounted to 1,740,655 barrels, against 3,295,580 barrels for the same period last year. For the month of May 1932 the production was 530,504 barrels, against 1,090,449 barrels in May 1931.

Cement Production in Finland.

It is reported that cement sales in Finland amount to about 25 per cent. of the capacity of the cement plants in that country.

Cement Sales in France.

The total sales of all types of cement in France for the year 1931 amounted to 6,658,430 tons, compared with 6,204,599 tons in 1930 and 5,799,727 tons in 1929. The total includes 4,971,479 tons of artificial Portland cement, 777,321 tons of natural Portland cement, 658,532 tons of slag cement, 183,270 tons of Roman cement, and 67,828 tons of aluminous cement.

Soc. des Materiaux de Construction de la Loisne report an increase of 7.5 per cent. in the sales of cement for the first eight months of this year, compared with the same period last year.

The sales of Etablissements Poliet et Chausson increased by 20 per cent. during the month of August 1932, when the new works at Lormont were put into operation.

Cement Production in Italy.

For the period January to July 1932 the total production of cement in Italy amounted to 1,739,803 tons, against 1,774,861 tons for the same period of 1931

and 2,008,149 tons for this period of 1930. For the months of July 1932, 1931 and 1930 production was 316.297 tons, 302,725 tons, and 331,316 tons, respectively.

Cement Sales in Germany.

For the period January to September 1932 the sales of the Deutscher Zement Bund were 2,270,000 tons, compared with 3,127,000 tons and 4,527,000 tons for the same period in 1931 and 1930, respectively. For the month of September the sales were 283,000 tons, against 343,000 tons and 510,000 tons in September 1931 and 1930.

It is reported that Portland-Zement-und-Kalkwerke Sachsen-Anhalt A.G. has closed its plant at Nienberg, which has a capacity of 180,000 tons per annum.

Proposed New Persian Cement Plant.

It is reported that the Persian Government has given permission to a German firm to erect a cement factory in the vicinity of Teheran on condition that the factory is ready to operate within eight months.

Australian Cement Companies.

The Kandos Cement Co., Ltd., showed a profit of £14,820 for the year ended June 30, 1932, and declared a dividend of 2½ per cent.; these figures compare with profits of £43,762 and £178,340, and dividends of 5 per cent. and 10 per cent. for the years 1931 and 1930, respectively.

The Standard Portland Cement Co., Ltd., of Sydney, made a profit of £22,257 for the year ended June 30, 1932, against £39,541 for 1931 and £47,872 for 1930. The dividend of 4 per cent. paid for the year ended June 30, 1932, compares with 5½ per cent. for 1931 and 8 per cent. for 1930.

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CEMENT MANUFACTURE
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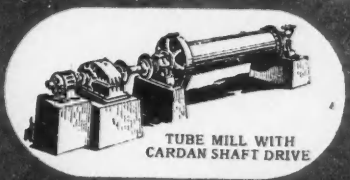
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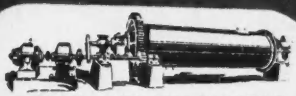
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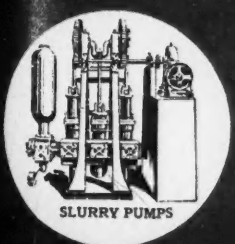
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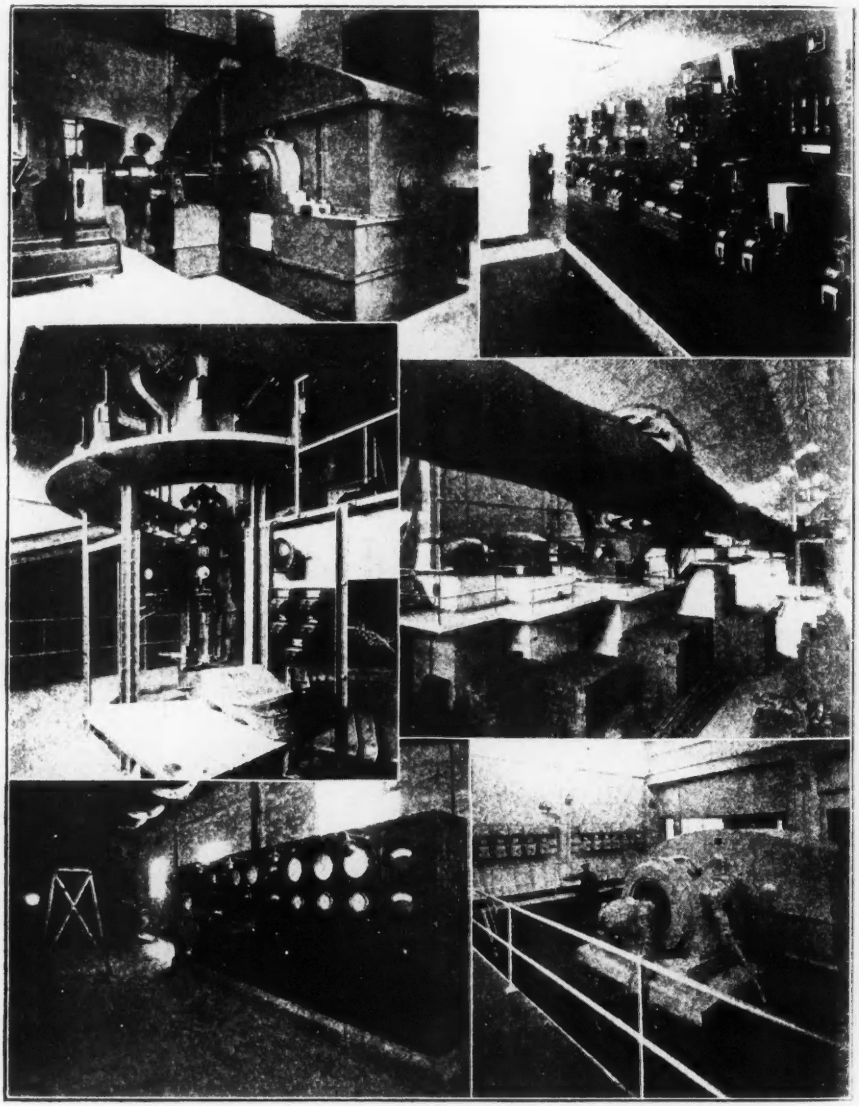

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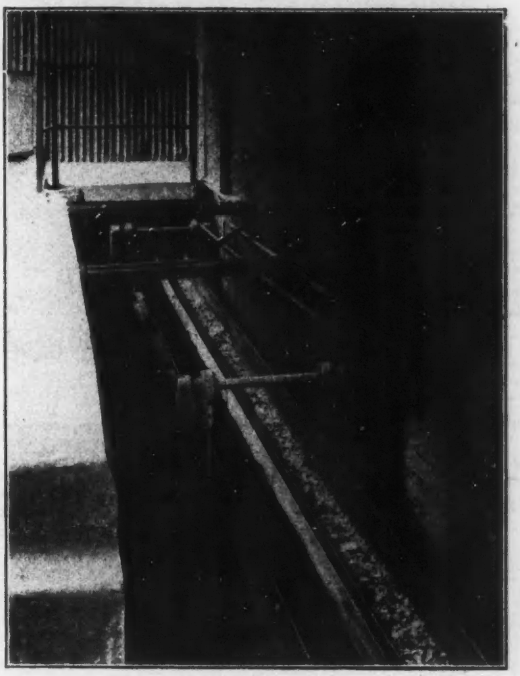

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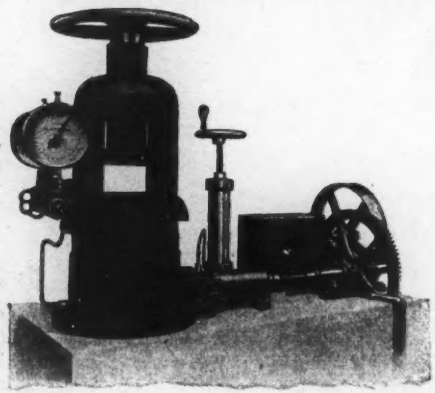

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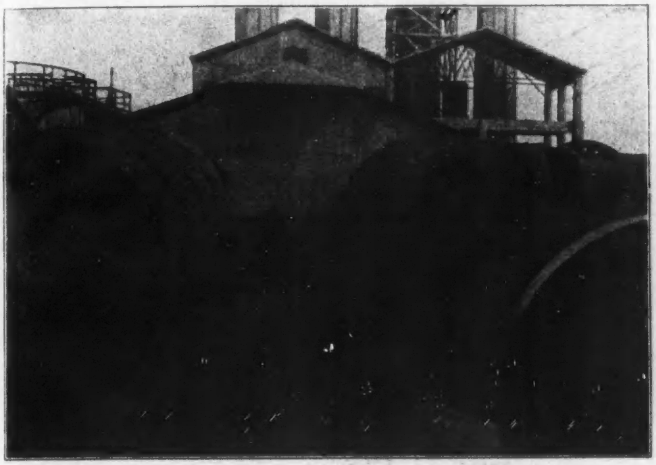

ROTARY KILNS WITH ENLARGED CALCINING ZONES (PATENTED) SAVE FUEL AND PRODUCE A UNIFORM CLINKER. THE ABOVE ILLUSTRATION SHOWS TWO OF A BATTERY OF FOUR LARGE KILNS WORKING ON THE "WET" PROCESS.

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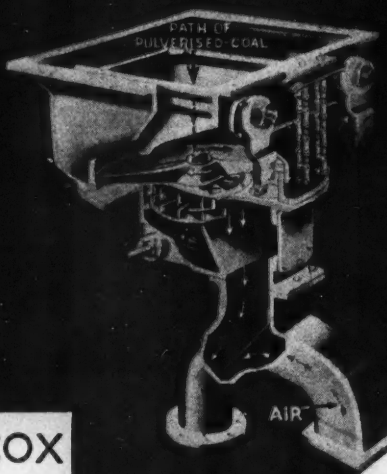

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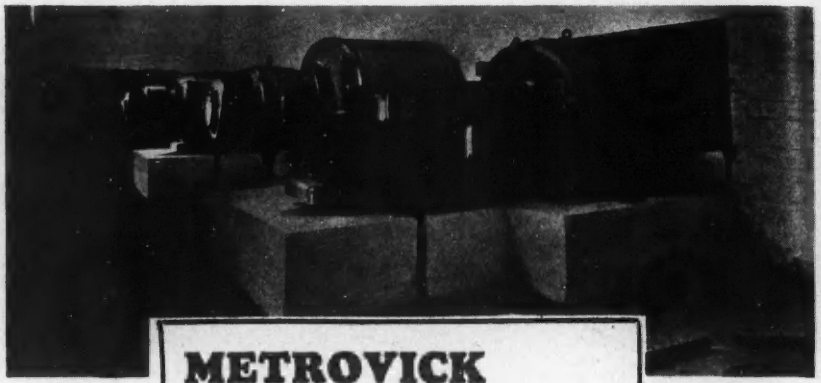

The above illustration shows the Mill Motor House at the Green Island Works with two Metrovick 475 H.P. Synchronous Induction Motors driving through Reduction Gears.

METROVICK EQUIPMENTS at GREEN ISLAND

CEMENT WORKS, HONG-KONG

AGGREGATE OUTPUT OF MOTORS 5,400 H.P.

108 MOTORS
6 TRANSFORMERS
13 SWITCHBOARDS

108 Metrovick Motors and the necessary Control Gear, together with 6 Transformers and 13 Switchboards are installed at Green Island Cement Works, Hong-Kong.

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METROPOLITAN Vickers ELECTRICAL CO. LTD.

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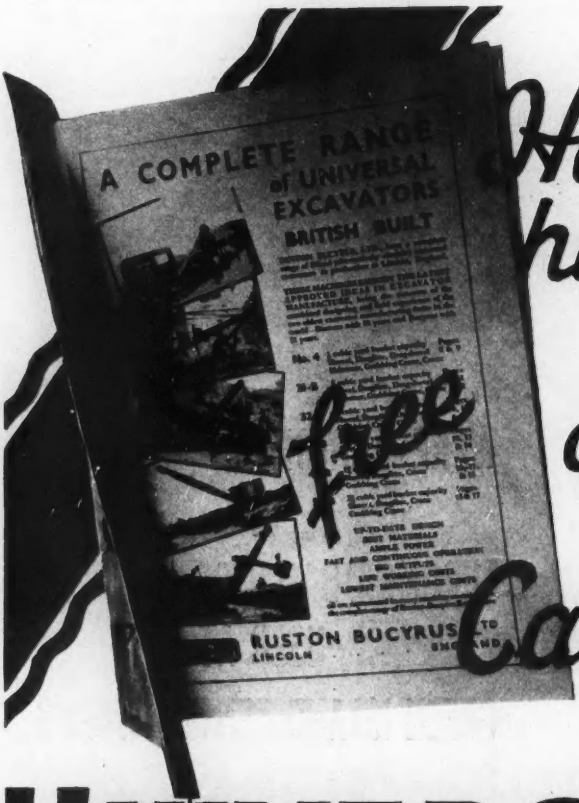

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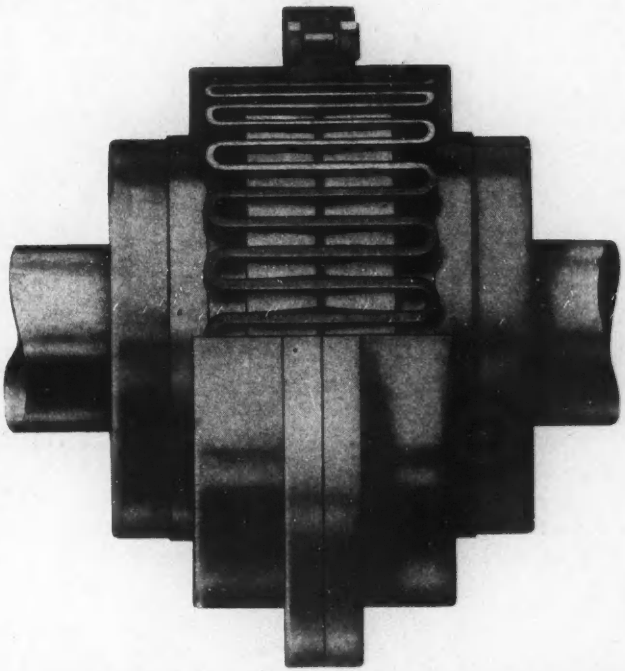

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Illustrations

Top left : Rotary Reflex Kilns 7′ 9″ × 11′ 0″ × 9′ 0″ diameter, 254′ 0″ long.

. . . .

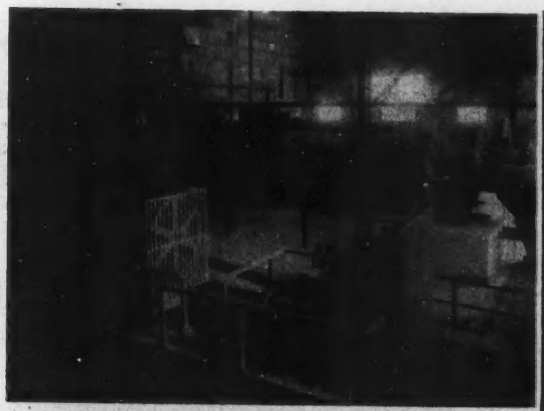
Bottom left : Air Swept Coal Grinding Plant.

. . . .

Top right : Raw Material Grinding Plant. Three 6′ 6″ dia. × 40′ 0″ long Wet Compound Tube Mills.

. . . .

Bottom right : Clinker Grinding Plant. Three 6′ 6″ dia. × 36′ 0″ long Compound Tube Mills.



On next page

Top : View of Works from the Sea.

. . . .

Bottom : View of completed Works.

. . . .

Photographs by courtesy of the Green Island Cement Co.

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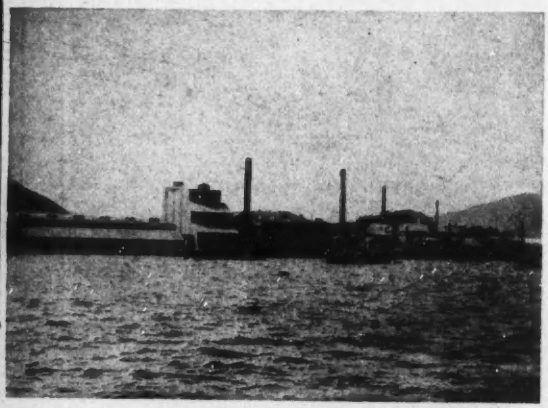

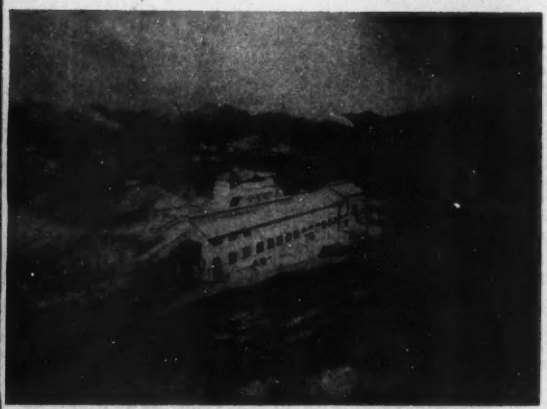

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Visco-Beth Dust Collector partially erected before despatch to Hong-Kong

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DUST-COLLECTORS
FOR THE
GREEN ISLAND CEMENT WORKS

OVER 99% EFFICIENCY

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In the mill house, suction bag-filters are installed at each point of discharge from the clinker belt and the gypsum belt, and also at the weighing machine, and this dust is all collected into one main flue. A second main flue takes the dust from each mill discharge and the cement elevators. This dust-laden air is drawn through stocking filters, and is transferred to the bulk cement passing to the silos.

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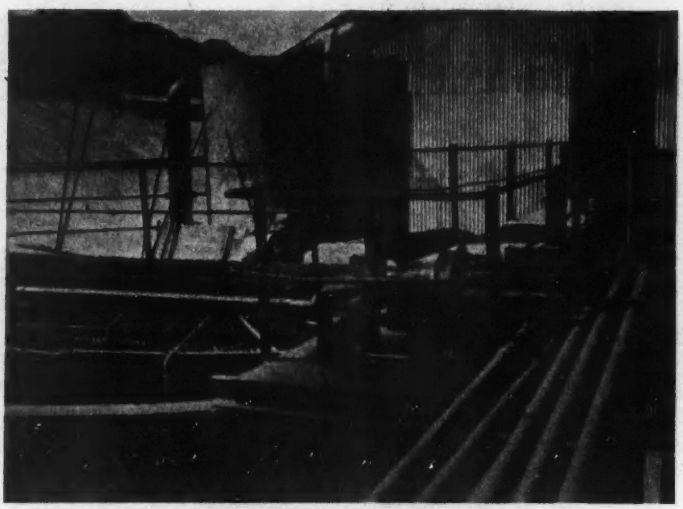

12-Way Reavell Sequence Valve positioned on Slurry Tank gangway at Green Island Cement Works.

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AT GREEN ISLAND CEMENT WORKS ARE AUTOMATICALLY CONTROLLING AIR SUPPLY TO AIR AGITATED SLURRY TANKS.

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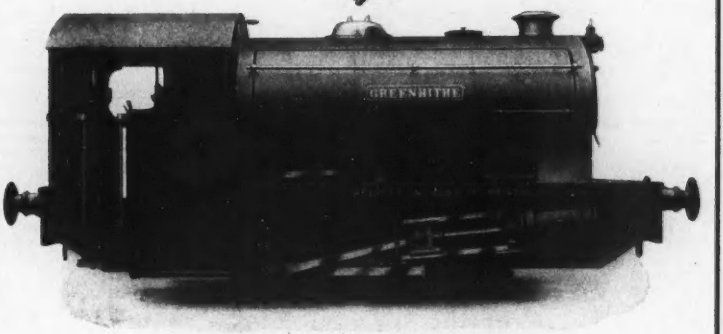
THE CEMENT INDUSTRY'S MOST POPULAR LOCOMOTIVE IN USE AT THE GREEN ISLAND CEMENT WORKS



Cement Works Engineers are invited to consult us on their locomotive problems. Our locomotives are in use in several cement works in this country, and because of their unfailing duty under the most severe conditions, and their low running costs, they were ordered for the new Green Island Cement Works at Hong-Kong.

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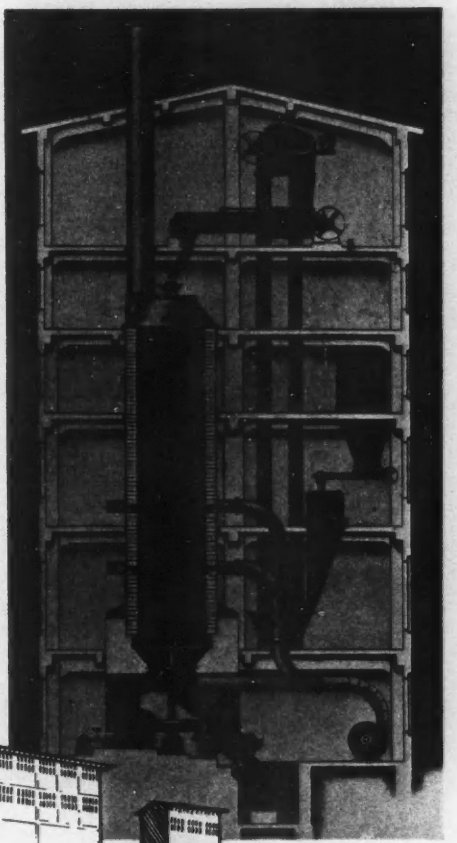

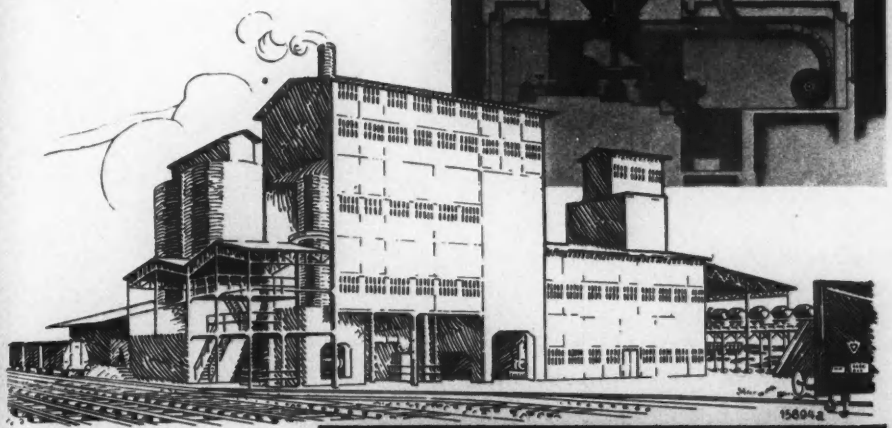

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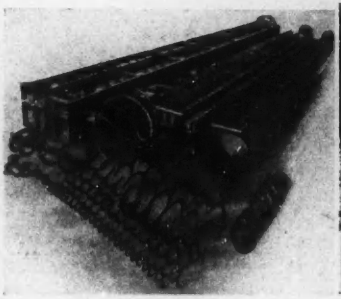

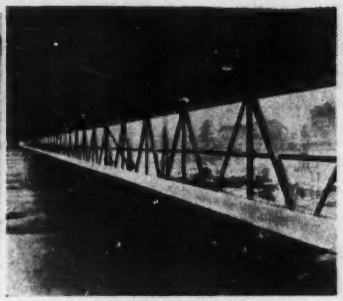

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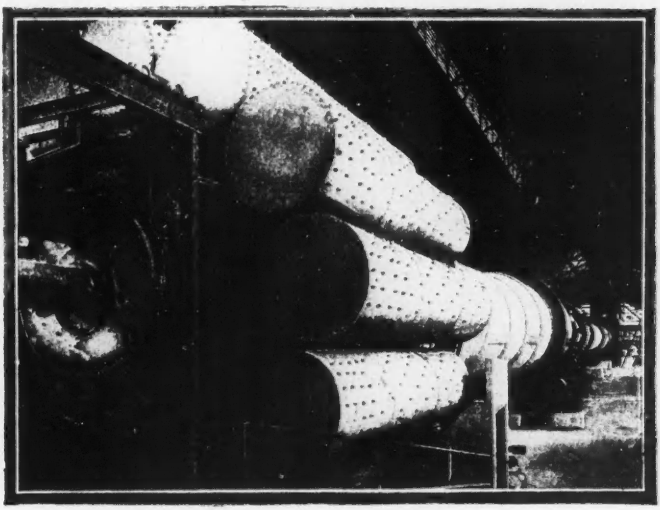

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"CEMENT CHEMISTRY IN THEORY AND PRACTICE"

By Prof. Dr. HANS KÜHL *(Director of The Institute for Cement Research, Berlin)*

List of Chapters

I.—The Development of Cement Research.
II.—The Theory of Cement Burning.
III.—The Constitution of Portland Cement Clinker.
IV.—The Problem of Hardening and its Signification in Cement Research.
V.—The Chemistry of High-Strength Cements.
VI.—The Technical Aspect of High-Strength Cements.

Dr. Hans Kühl is one of the foremost cement chemists of the world. In this book he exposes the misleading conclusions that have resulted from much of the cement research work of the past, and presents the most up-to-date knowledge on the subject in language readily understandable by the average reader. Dr. Kühl has been an important contributor to the research work on these subjects, some of his work covering a period of twenty years, and this enables him to write as an expert.

As the originator of what may be described as the miniature method of testing described in the book, Dr. Kühl has been the means of connecting the purely scientific work of the laboratory with the manufacturing or technical procedure. Previous investigations have been either the highly-specialised work of physical chemists whereby pure compounds thought to exist in cement have been synthesised and identified by optical constants (but without reference to commercial value as evidenced by strength tests), or the trial-and-error type on the commercial scale which have led to no advance in chemical knowledge. It has been generally admitted that the latter investigations have led to more fruitful results than the the purely scientific work, the production of rapid-hardening cement being a notable example of this. By his technique, however, Dr. Kühl has combined the two methods of investigation, and with no more than three grammes of cement prepared in the laboratory under scientific conditions he is able to apply tests which permit the tensile and comprehensive strengths of the material to be revealed. Similarly small quantities suffice for setting and soundness tests.

The author exposes the misleading conclusions that have resulted from two conditions prominent in much of the cement research work of the past. The first is the examination of the three-component system (lime-silica-alumina) without due regard for the differences caused by the presence of iron oxide acting as a catalyst or flux, and the second is the common procedure of immersing a few grains of cement in a comparatively large volume of water and assuming that the physical and chemical reactions are similar to those that occur in the practical application of cement when the proportion of water to cement is essentially different.

Two chapters are devoted to the chemistry and manufacture of rapid hardening cement, and more information on this important subject is given than has previously been available to the public. The question is here discussed of the influence of particle size upon strength of cement, and many readers will learn with surprise that there is a limit beyond which fineness of grinding can be continued without advantage to the strength of cement.

Another subject little known to English readers is that of "K.L. storage" of test pieces, *i.e.* the alternate storage in water and air which constitutes a soundness test and may reveal inherent instability in a cement not detected by the ordinary soundness tests.

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